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U.S. DEPARTMENT OF COMMERCE
National Oceanic and Atmospheric Administration
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PREFACE

This report was prepared during 1977-78 for the Pacific Fishery Management Council. The Council is one of seven regional councils established by the Fishery Conservation and Management Act of 1976, and is responsible for developing management plans for marine fisheries off the coasts of California, Oregon and Washington. Northern anchovy was the second species (after salmon) to come under management by the Federal government through Pacific Fishery Management Council efforts. Regulations for northern anchovy fishing were first promulgated in September 1978 and have been twice amended since then.

It will be obvious to most readers that the following material is organized into categories of information and findings which satisfy the requirements for fishery management plans. Despite the fact that the report is designed as a management plan rather than a scientific publication, the summary of information is worthy of distribution on its own merit. The informational and analytical sections of the fishery plan are, therefore, presented here with essentially no editing. Only the adopted management program and the public hearings summary have been deleted from the original document which was printed in the Federal Register on July 21, 1978 (Volume 43, No. 141, Book 2, pp. 31651-31879).

While the management regulations continue to be amended in various ways, corresponding to changing conditions and viewpoints, most of the information contained herein will continue to be of interest.

Daniel D. Huppert
April 1980

TABLE OF CONTENTS

Table of Contents (continued)

Table of Contents (continued)

2.0. Introduction

The Fishery Conservation and Management Act of 1976 (Public Law 94-265) provides for the United States' exclusive fishery management authority over the fishery resources within a Fishery Conservation Zone extending from the seaward boundary of the United States' territorial sea (3 miles from shore) to a point 200 miles from shore. The responsibility for developing management plans for the fisheries in the Zone is vested in eight Regional Fishery Management Councils. The Pacific Fishery Management Council is responsible for the fisheries off the coasts of the states of Washington, Oregon and California. Implementation and enforcement of any regulations pertinent to fisheries management within the Fishery Conservation Zone are the responsibility of the Secretary of Commerce. The Anchovy Fishery Management Plan was developed for and by the Pacific Fishery Management Council and is submitted to the Secretary of Commerce for approval and implementation.

The successful implementation of the Anchovy Fisheries Management Plan will require unity of purpose between the Federal management regulations and the regulations enforced by the State of California. Authority for implementing fishery management regulations in California resides with the State Legislature and the California Fish and Game Commission. Enforcement of California fishery regulations is accomplished by the California Department of Fish and Game (CF&G).

Because the Fishery Management Plan is directed toward a fish stock which resides in the fishery conservation zone of Mexico as well as in the United States' Zone, cooperation and common objectives between the United States and Mexico will be necessary to the successful international management of the anchovy resource. At the very least, the two countries should share an overall objective with respect to total annual harvests from the stock. Bilateral negotiations between the United States and Mexico on fisheries management matters are the responsibility of the United States' Secretary of State with the advice and council of the Secretary of Commerce and the Fisheries Management Council whose authority covers the U.S. portion of the shared fishery resource.

The management unit chosen for this Plan is the central subpopulation of northern anchovy (*Engraulis mordax*) which extends from approximately San Francisco to Punta Baja, Baja California, Mexico. Biological aspects of the northern anchovy are reviewed and the maximum sustainable yield of the fish stock is estimated at 484 thousand short tons per year. The great variability of the anchovy biomass, independently of the effects of a commercial fishery, makes the management of this fishery subject to a level of uncertainty which calls for flexibility in setting annual allowable yield and a conservative stance in relation to preserving sufficient reproductive potential in the standing biomass to assure continued productivity of the stock.

3.0. Description of Fishery

3.1. Areas and Stocks Involved

The commercial fisheries in Southern California for pelagic schooling fish are conducted by fishing vessels using various round haul gear, typically purse seines and lampara nets. Many of the vessels are remnants of the collapsed Pacific sardine fishery. The major species in this fishery are the northern anchovy, *Engraulis mordax*; jack mackerel, *Trachurus symmetricus*; bonito, *Sarda chiliensis*; bluefin tuna, *Thunnus thynnus*; and market squid, *Loligo opalescens*. To a much lesser extent Pacific mackerel, *Scomber japonicus*, and a variety of other incidental species are taken. Development of an integrated set of management plans that cover most of these species is a long-term goal. The development of a management plan directed specifically at northern anchovy has been assigned first priority. Consequently, it is the fishery of the northern anchovy that is addressed by this management plan.

The northern anchovy, *Engraulis mordax* Girard, is a common pelagic schooling fish of the west coast of North America that ranges from Queen Charlotte Islands (Miller and Lea, 1972, p. 56) to essentially Magdalena Bay, Baja California (Ahlstrom 1968, p. 69 and Mais 1974, p. 50). Hubbs (1925, p. 18) identified a subspecies, *Engraulis mordax nanus*, in San Francisco Bay, but this subspecies, if it actually exists, is very minor relative to the northern anchovy population. The population has been divided into northern, central and southern subpopulations based on variations in meristics (McHugh 1951, p. 157) and electrophoretic separation of the blood serum protein, transferrin (Vrooman and Paloma 1975, p. 2), as shown in Figure 3.1-1.

The northern subpopulation occurs off Oregon, Washington and northern California. Richardson (1973, p. 708) has found anchovy eggs and larvae off Oregon but has recently concluded that early larva development is successful only offshore beyond the continental shelf (Richardson and Pearcy, 1977, p. 42). Tillman (1974, p. 214) determined from length frequency samples of trawl-caught anchovies taken off Washington and Oregon in the winter and spring of 1966 and 1967 that 0-age anchovies were present in the survey area. From this he concluded that successful spawning had occurred in the summers of 1965 and 1966 and that the northern subpopulation has self-sustaining capability.

Apparently, anchovies move seasonally in and out of the bays and estuaries in the northern area. Juvenile anchovy probably use these inshore areas as nursery grounds, but they are not areas of significant spawning (S. Richardson, pers. comm., 2-15-77). Minor fisheries for anchovy of the northern subpopulation supply bait for albacore and recreational fisheries and take place nearshore in the vicinity of estuaries.

The boundary between the northern and central subpopulations is not well defined. Occasional surveys off California north of San Francisco have not found anchovies in abundance (Frey 1971, p. 49 and Mais 1974, p. 21).

The percentages of the transferrin alleles from blood samples taken from anchovies in Humboldt Bay and nearshore at Salt Point, latitude 38°34', were similar to those for anchovies from Newport Bay, Oregon (Vrooman and Paloma 1975, p. 5). Two samples they collected from San Francisco Bay were classified as central subpopulation. Of the three samples from Monterey, California, one was identified as northern subpopulation. Sampling in the boundary area between the two subpopulations has been nearshore and too sparse to define the division. The boundary probably fluctuates seasonally and annually in the area just north of San Francisco approximately 38°N.

The central subpopulation, the most abundant of the three subpopulations (Vrooman and Smith 1971, p. 51), extends from 38°N to approximately 30°N at Punta Baja, Baja California, in the south. The portion of the subpopulation north of Point Conception is continuous with the southern portion. Vrooman and Paloma (1975, p. 6) found no difference in the ratio of transferrin alleles between these areas. Spratt (1972, p. 19) could not detect any difference in the relationship of otolith weight to fish length for anchovies between the two areas. Mais (1974, p. 25) found only a slight increase in average length for given age in the northern portion of the central subpopulation. Tagging conducted in the late 1960's demonstrated anchovies move between the two areas of the central subpopulation in both a northerly and southerly direction (Haugen, Messersmith and Wickwire, 1969, p. 81 and 82). The overall tag recovery rate was relatively low.

The bulk of the biomass in the central subpopulation is consistently located in the Southern California Bight, an approximate 20,000 sq. n. mi. area bounded by Point Conception, California in the north to Point Descanso, Mexico, in the south, and a series of banks and islands extending in a northwest-southwest direction from San Miguel Island to the Sixty-Mile Bank (Mais, 1974, p. 29). Anchovy eggs and larvae are frequently taken in abundance offshore as far as 200 miles (Smith 1972, p. 869) (see Figure 3.1-2.) Based on the years 1951-1975 the estimated number of anchovy larvae from the egg and larva surveys, on the average, 50.7% of the anchovy spawning biomass is in the Southern California Bight. This percentage is consistent for the survey years 1969, 1972 and 1975, although the percentage has fluctuated from 97% in 1957 to 17% in 1961 (Fig. 3.1-3). The San Pedro and Port Hueneme anchovy reduction fisheries take place in the channel area of the Southern California Bight bounded in the north and west by the city of Santa Barbara and Santa Cruz Island and to the south and east by Santa Catalina Island and Dana Point, an area approximately 90 miles long and 22 miles wide or 2,000 sq. n. mi. The commercial harvest of anchovies also takes place to a smaller extent in Monterey Bay. Based on the more recent sea surveys conducted by California Dept. of Fish and Game, on the average, 30.9% of the anchovies monitored by acoustics in the Southern California Bight were inside the area described as the channel. An estimate of the average proportion of the central subpopulation in the channel then is 50.7% times 30.9% or 15.7%, approximately 1/6th of the central subpopulation.

The division between the central and southern subpopulations is relatively well defined although the offshore area has not been sampled adequately. Vrooman and Paloma (1975, p. 6) found a distinction in the percentages of transferrin alleles between 29°33'N and 28°33.2'N from a series of 10 samples taken between 30°50.5'N and 27°04'N. Differences in mean length at age for anchovies north and south of this zone support this division (Mais 1974, p. 53). The actual location of this division in any 1 year probably depends on the environmental conditions.

The southern subpopulation extends south from approximately 30°N, Punta Baja to approximately 24°N, Magdalena Bay (Ahlstrom 1968, p. 68 and Mais 1974, p. 50). Mais (1974, p. 53) found that anchovies in the southern subpopulation are considerably smaller for their age, shorter lived and attain less maximum length than anchovies in the central subpopulation. This subpopulation is harvested to some extent by the Mexican anchovy fishery. The percentage of the anchovy catch attributed to the southern subpopulation can be determined from commercial catch samples for length and age frequency distributions and from knowing the location of capture. The partitioning of the Mexican harvest into southern and central subpopulations will be important in the international management of the anchovy resource.

In conclusion, the central subpopulation ranges from approximately 38°N, just north of San Francisco, California, to approximately 30°N, near Punta Baja, Baja California, Mexico, and extends offshore to approximately 200 miles. The central subpopulation is relatively homogeneous throughout its range and yet is distinct from both the northern and southern subpopulations. The central subpopulation is the target of both Meixcan and American anchovy fisheries. For these reasons, the management unit for this anchovy management plan is limited to the central subpopulation.

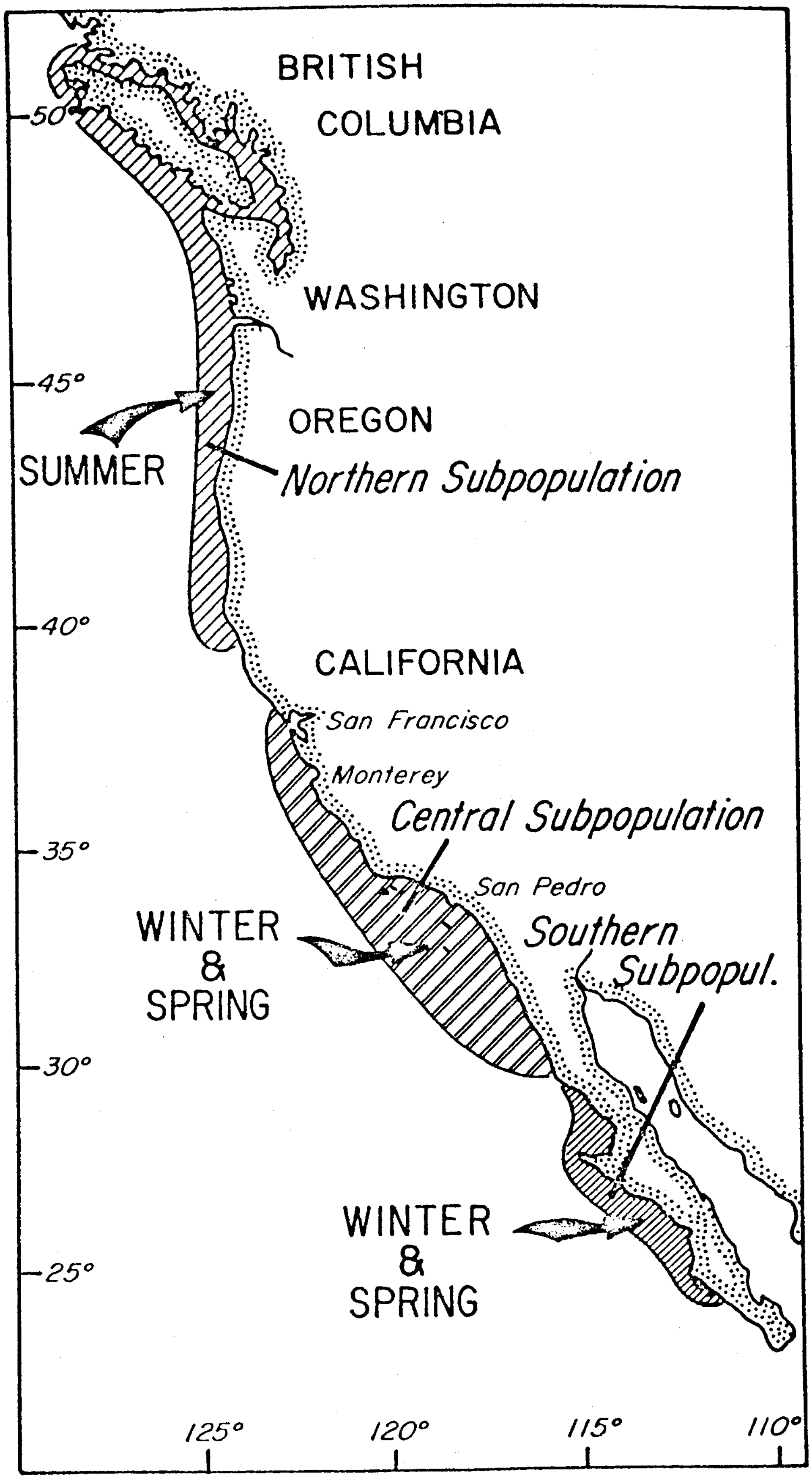

Figure 3.1-1. Geographic distribution and spawning seasons of the three subpopulations of northern anchovy, *Engraulis mordax*.

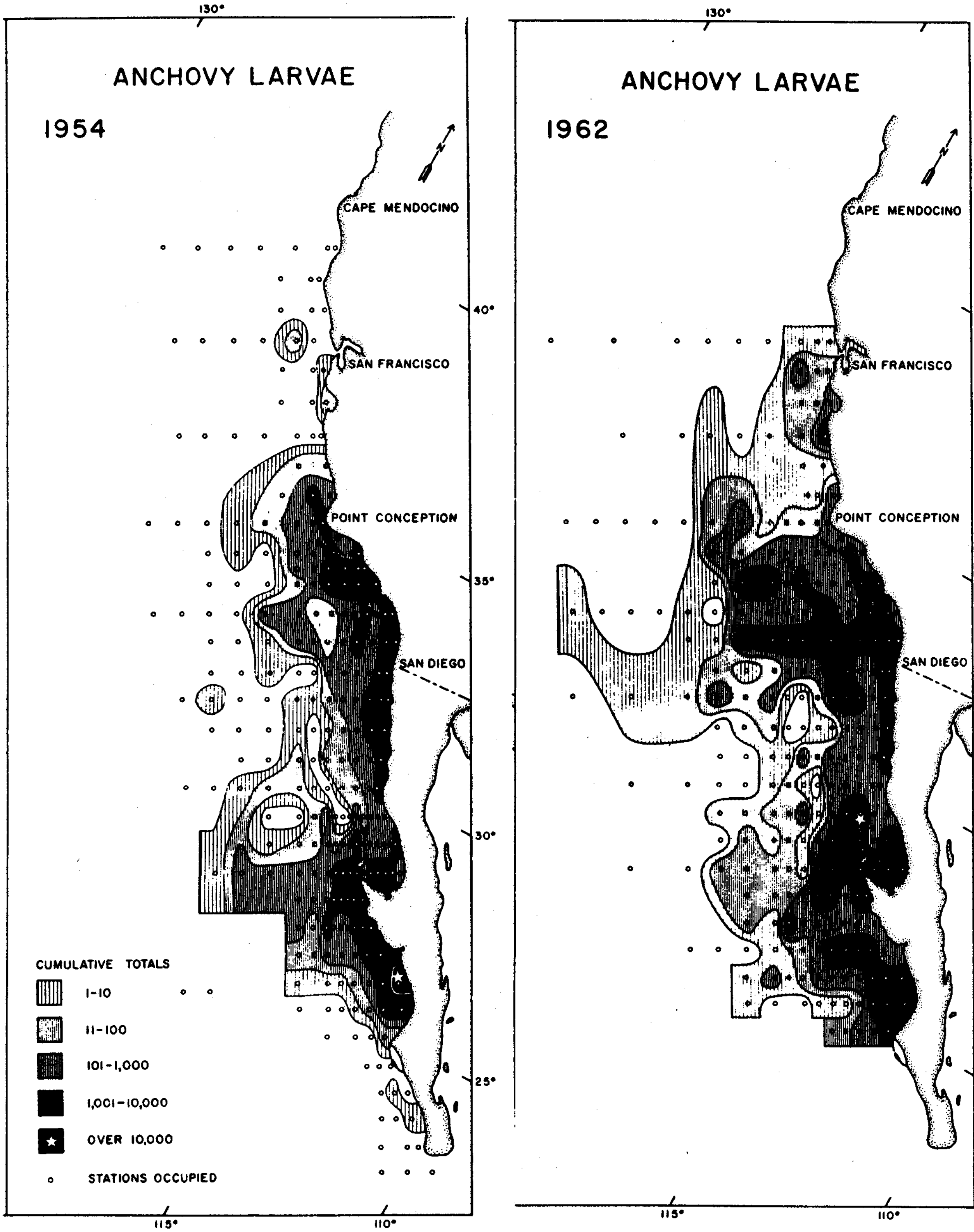

Figure 3.1-2. Distribution of anchovy larvae for years 1954 and 1962 (from Ahlstrom 1966). Legend is number of larvae per 10 square meters.

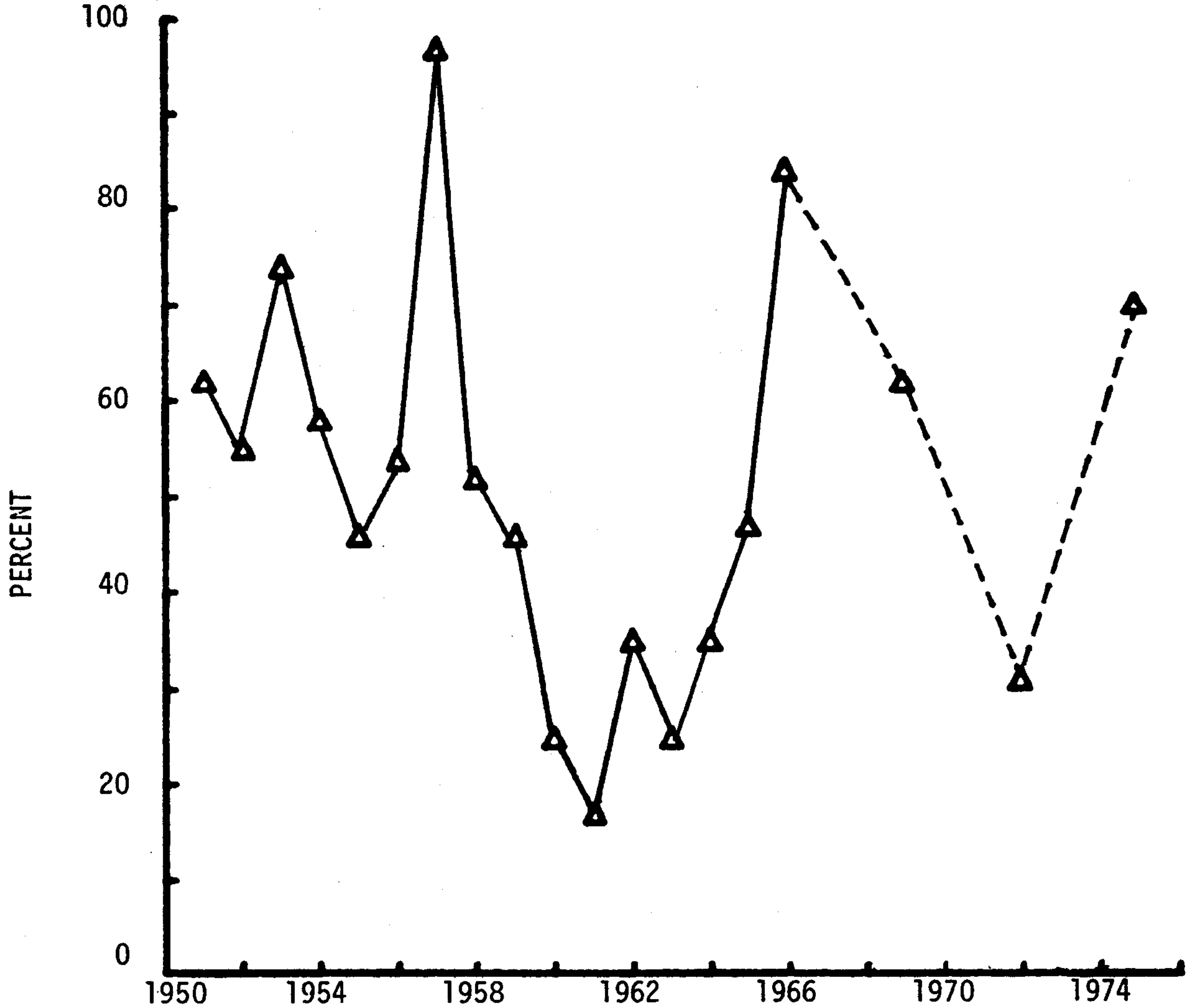

Figure 3.1-3. The percentage of central subpopulation anchovy larvae occurring in the Southern California Bight.

3.2. History of Exploitation and Description of Fisheries

3.2.1. Domestic Commercial Fishery

The largest catches at present are taken by the commercial "wetfish" fleet which fishes for reduction purposes. This fleet also fishes for sardines, jack mackerel, Pacific mackerel, bonito, bluefin tuna and sometimes for market squid. This is basically the remains of the fleet that harvested the sardine. While the fleet fishes for other "wetfish" species, the anchovy catch accounts for the preponderance of the multi-species harvest.

Reliable records of commercial landings of northern anchovies, *Engraulis mordax*, used for human consumption, dead bait, feeding in fish hatcheries and mink farms, and reduction to oil and meal, date from 1916 (Table 3.2-1). During the earlier years of the fishery, annual landings averaged only 505 tons. Most of the catch from 1916 through 1921 was for reduction to oil and meal. In 1919 a law was passed prohibiting the reduction of whole fish except under permit. The law became very effective in 1921 and resulted in reduced anchovy landings which averaged 150 tons for the next 17 years. During the period 1939-1946, landings averaged 1,454 tons.

Scarcity of Pacific sardine, *Sardinops sagax caerulea*, caused processors to begin canning anchovies in quantity in 1946; and in 1947, the catch increased to 9,470 tons with landings exceeding canning needs and the excess deliveries being diverted to reduction plants. In order to lower the quantity of anchovies being reduced, the California Fish and Game Commission required each processor to place a large proportion of each ton of anchovies in cans (40-60% depending on can size). Anchovy canning declined with the temporary resurgence of the sardine population through 1951. With the collapse of the sardine fishery in 1952, anchovy landings again increased to 42,918 tons in 1953. Due to economic conditions, presumably low consumer acceptance of canned anchovies, and an upsurge of sardines in 1958, landings declined to 19,400 tons in 1957 and 5,200 tons in 1958. Landings remained below 5,000 tons through 1965.

In November 1965, the California Fish and Game Commission authorized a 75,000 ton anchovy harvest for reduction. Quotas ranging up to 165,000 tons have been authorized since 1965 (Table 3.2.-2). During the first four seasons, catches fell far short of the quotas. The third season (1967-1968) was a near failure with only 6,506 tons taken, almost all in the Monterey Bay area. A declining world price for fish meal and the resulting low price paid to fishermen for their catch, along with a lack of available anchovies close to port, were responsible for decreased landings. Economic conditions improved for the 1968-69 season, when 28,050 tons were landed, and continued to improve throughout the season. During the 1969-70 season, 83,467 tons were landed and the quota for the season was increased to 140,000 tons. The following year the quota was set at 110,000 tons and remained at that level for the next three seasons. During the 1973-74 season, the quota was reached and was increased to 135,000 tons. Reduction landings was established at 115,000 tons, but later in the season was increased to 130,000 tons. The 1975-76 quota was initially set at 115,000 tons and later raised to 165,000 tons.

Table 3.2-1. Yearly California Anchovy Landings

Year	Tons	Year	Tons
1916	266	1946	961
1917	264	1947	9,470
1918	434	1948	5,418
1919	805	1949	1,664
1920	285	1950	2,439
1921	973	1951	3,477
1922	326	1952	27,891
1923	154	1953	42,918
1924	174	1954	21,205
1925	46	1955	22,346
1926	30	1956	28,460
1927	184	1957	20,274
1928	179	1958	5,801
1929	191	1959	3,587
1930	160	1960	2,529
1931	154	1961	3,856
1932	150	1962	1,382
1933	159	1963	2,285
1934	129	1964	2,488
1935	90	1965	2,866
1936	98	1966	31,140
1937	113	1967	34,805
1938	368	1968	15,538
1939	1,074	1969	67,639
1940	3,159	1970	96,242
1941	2,053	1971	44,853
1942	847	1972	69,100
1943	785	1973	132,636
1944	1,946	1974	82,717
1945	808	1975	158,511

Table 3.2-2. Anchovy reduction fishery landings.
(short tons)

Seasons	1965	1966	1967	1968	1969	1970	1971	1972	1973	1974	1975	1976	Quota	Landings	No.Boats**
1965-66	171	16,672											75,000	16,843	30
1966-67		10,676	26,939										75,000	37,610	35
1967-68			5,409	1,098									75,000	6,503	41
1968-69				12,697	15,353								75,000	28,050	30
1969-70					49,851	33,616							140,000	83,473	31
1970-71						59,339	22,216						110,000	80,752	30
1971-72							21,436	31,991					110,000	53,449	38
1972-73								34,626	40,893				110,000	75,519	37
1973-74									89,655	30,983			135,000	120,638	40
1974-75										49,926	66,504		130,000	116,430	44
1975-76											87,702	53,334*	165,000	141,036	50
Total	171	27,348	32,347	13,795	65,204	92,955	43,652	66,617	130,548	80,909	154,206	53,334*		707,752	

* Through May 15, 1976 when the 1975-76 season closed.

** Boats landing at least one load of anchovies.

The anchovy fleet consists primarily of purse seiners that range in length from 38 to 100 feet. These vessels use round-haul nets (purse and lampara). Most of the southern California fleet use purse seine gear, while the vessels fishing in the Monterey Bay area mainly fish with lampara nets. For further descriptions, see Scofield (1951) and Knaggs (1972).

Fishing effort for anchovies is at the present time mainly in southern California waters. Some catches for reduction are made in Monterey Bay and are landed at Moss Landing. Several vessels land anchovies at Oxnard, but the major reduction landings are made at Terminal Island (San Pedro). The principal areas of catch are the Catalina Channel and the Santa Barbara Channel. The California fleet fishing anchovies for reduction has increased in size during the last few years (Table 3.2-2); however, the "basic" fleet has remained about the same and approximates 25 vessels. Fishing effort is somewhat controlled by processing capabilities. When fish are readily available, processing becomes the limiting factor and the fleet is put on daily landing limits.

Two non-reduction commercial fisheries represent only minor usage at the present time. A few anchovies are canned each year, and small quantities are "fresh-frozen" for human consumption. While these two groups currently utilize very limited quantities of anchovies, they do represent potential harvest.

Expansion of the southern California anchovy reduction fishery would likely divert some fishing effort from other species fished by the round-haul fleet (primarily jack mackerel and squid, and to a smaller extent Pacific mackerel, Pacific bonito, and bluefin tuna). A moderate expansion of the anchovy fleet, which would be expected, would probably have very little long-term effect on fishing pressure on the alternative target species.

3.2.2. Domestic Live-Bait Fishery

The live-bait industry consists of the harvest, maintenance, and sale of small, live marine fish to anglers for use as bait and/or chum. This unique fishery had its introduction in southern California in 1910 by Japanese albacore fishermen who employed blanket nets to capture small forage fish in their fishing operations. In 1912, the lampara net was introduced into the fishery and sport boats carrying anglers to the offshore fishing grounds began using their own nets to capture bait.

As the sport fishing industry grew, the demand for live bait also increased, causing a greater degree of specialization in boats and nets, and in the methods of locating and distributing the live bait. Shortly after WW II, the demands for live bait became sufficient to support a fleet engaged solely to supply bait. This fishery is important today because the most prized sport fishes usually prefer live bait to any other offering.

The live-bait fishery is located principally in southern California with smaller fisheries at Morro Bay and San Francisco. The mainstay of the live-bait fishery has always been anchovies, but prior to the virtual disappearance of the sardine, as much as 15 to 20% of the bait consisted of young sardines. Since 1957, when the last large influx of young sardines was observed, anchovies have comprised 98-99% of the live-bait catch. The remainder of the catch is comprised of white croaker, queenfish, Pacific sardine, jack mackerel and Pacific mackerel.

In recent years, the live-bait fishery has landed between 5,300 and 6,400 tons of bait each year (Table 3.2-3). During 1975, between 40 and 45% of the live bait taken in waters off California was caught off San Diego. Between 20 and 25% was taken off San Pedro, while Santa Monica Bay and waters off Newport each yielded from 10 to 20% of the total catch. Less than 5% of the total catch was taken in each of the following areas: Morro Bay-Avila, Port Hueneme and Oceanside.

During the period 1947 to 1969, the number of live-bait fishermen gradually declined as overhead costs and lack of good contracts took their toll of the small independent bait operator. The number of boats reporting their catch to the California Department of Fish and Game were from a high of 30 boats in 1940 to a low of 10 boats in 1969. At the present time, there are 14 bait operators who supply virtually the state's entire live-bait catch (Table 3.2-3). Some of these fishermen also participate in the anchovy reduction fishery.

This small but important fleet is faced with a difficult logistical problem. Daily commitments of quality bait during peak sport fishing activity exert a great deal of pressure. Bait haulers, by necessity, must fish relatively close to home. When live bait becomes scarce or of poor quality locally, the amount of effort (time) expended to fish elsewhere and transport their catch can be considerable. During some years, the albacore fleet used anchovies for chumming albacore. This bait may be purchased from the live-bait industry, or, in many cases, be caught by the albacore fishermen. These "baiting" activities occur at a number of ports in California.

The seasonal distribution and behavior of the northern anchovy often has a major influence on the live-bait industry. Historically, live-bait dealers have had difficulty meeting their commitments during the summer months. Whenever live bait becomes scarce, a great deal of anxiety within the recreational fishing industry surfaces and there seems little that can be done to allay fears of overfishing.

In past years, when bait shortages occurred during summer months, Los Angeles-Long Beach Harbor usually proved an exception and many live-bait fishermen along the coast depended on this traditional fishing area for their bait. In some years, the harbor provided as much as 30% of all live bait caught and was the mainstay of the live-bait fishery in southern California. In particular, the 1957, 1963, 1965 and 1966 summer seasons found the majority of bait boats fishing the harbor throughout the summer months. Between 1956 and 1966 boats from as far away as San Diego were forced to fish Los Angeles Harbor on numerous occasions for five out of the ten seasons.

In some years, the quality of bait creates as many problems for the fishermen as a shortage of bait. In 1957, 1958 and 1959, tremendous quantities of "pinheads" (small, juvenile fish) moved inshore along the southern California coast and plagued the live-bait fishermen. At the same time, fishermen's observations, stomach analysis of offshore fish (tuna), and research cruises indicated large anchovies were abundant offshore in deeper waters where the lampara nets of the bait fishermen cannot work efficiently. Bait fishermen were forced to expend additional inshore effort in order to secure quality bait during these seasons.

Table 3.2-3. Commercial landings and live-bait catch of anchovies in tons in California 1939-1975.

Year	Commercial landings*	Live-bait	Total	Percent live-bait	Number of live-bait boats reporting
1939	1,074	1,503	2,577	58.8	
1940	3,159	2,006	5,165	35.8	30
1941	2,052	1,582	3,634	43.5	
1942	847	258	1,105	23.3	9
1943	785	-	-	-	-
1944	1,946	-	-	-	-
1945	808	-	-	-	-
1946	961	2,748	3,709	74.1	-
1947	9,470	2,854	12,324	23.2	-
1948	5,418	3,725	9,143	40.7	25
1949	1,661	2,802	4,463	62.8	23
1950	2,430	3,824	6,263	61.1	25
1951	3,477	5,142	8,619	59.7	22
1952	27,892	6,810	34,702	19.6	24
1953	42,918	6,391	49,300	13.0	30
1954	21,205	6,686	27,891	24.0	23
1955	22,346	6,125	28,471	21.5	22
1956	28,460	6,332	34,792	18.2	18
1957	20,274	4,110	24,384	16.9	17
1958	5,801	4,236	10,037	42.2	24
1959	3,587	4,737	8,324	56.9	16
1960	2,529	4,657	7,186	64.8	13
1961	3,856	5,913	9,769	60.5	16
1962	1,382	6,167	7,549	81.7	22
1963	2,285	4,442	6,727	66.0	23
1964	2,488	5,191	7,679	67.5	22
1965	2,867	6,223	9,090	68.5	24
1966	31,140	6,772	37,912	17.8	18
1967	34,805	5,399	40,204	13.4	16
1968	15,538	7,324	22,862	32.0	19
1969	67,639	5,391	73,030	7.4	10
1970	96,242	6,110	102,352	5.9	11
1971	44,853	6,387	51,240	12.5	11
1972	69,100	5,850	74,950	7.8	12
1973	132,636	5,944	138,580	4.3	12
1974	82,717	6,318	89,035	7.1	14
1975	158,511	5,370	163,881	3.3	14

*For all uses

The live-bait fishermen use lampara nets almost exclusively. The lampara net is a forerunner of the purse seine, but lacks the ability to close or "purse" the bottom of the net to prevent the fish from escaping. Therefore, lampara nets are usually used in shallow waters where the sea bottom serves this purpose. The use of such nets forces live-bait fishermen to fish in inshore areas, and does not allow them to catch offshore fish efficiently, even when they are abundant. Use of purse seine gear would ideally improve the bait fishermen's ability to supply live bait, however, the purse seines that have been tried have tended to injure the fish, thus severely reducing survival in the bait wells. It appears likely that many of the problems of bait availability can be overcome through improvements in gear technology.

3.2.3. Mexican Fisheries

There are basically two user groups involved in the harvest of northern anchovies in Mexico. Both these groups are based in Ensenada, Baja California at the present time. The recreational fishery uses anchovies as bait for partyboats and for individual sportsmen. The commercial fishery is conducted by boats based at Ensenada. The anchovies are used for reduction and canning; and a small amount may be taken for use by the albacore fleet.

Mexico's utilization of the anchovy resource off her west coast has increased considerably during the last few years (Table 3.2.-4) with the increase in the processing capabilities at Ensenada as well as the size and quality of the fishing fleet; landings for the reduction fishery based in this port should continue to increase during the next few years. At present, there are plans to locate another reduction plant in the Ensenada area and to add several large purse seiners to the reduction fleet.

The Mexican commercial fishing fleet contains a number of rather small purse seiners averaging less than 50 tons hold capacity. These vessels fish close inshore and relatively close to Ensenada. Part of the fleet consists of larger vessels that fish for anchovies part of the year, then move to the Gulf of California to participate in the sardine fishery. Six large purse seiners of 300 net ton capacity joined the anchovy fleet in 1976. These vessels will fish anchovies on an all-year basis.

While a large portion of the catch landed at Ensenada is from the central stock, part of the catch is made up of fish from the southern stock.

Table 3.2-4. Anchovy landings at Ensenada, Baja California. (short tons)

1965	10,230	1970	5,565
1966	14,470	1971	4,126
1967	24,750	1972	6,682
1968	17,267	1973	2,310
1969	4,239	1974	47,766
		1975	60,862
		1976*	78,693

* preliminary

3.3. California Management Regime

3.3.1. Management institutions, policies and jurisdictions

3.3.1.1. Domestic

Management of the anchovy fishery by the state of California is divided among three bodies: the California state legislature, the California Fish and Game Commission, and the California Department of Fish and Game. The state legislature is responsible for making laws governing most commercial fishing activities, including take of anchovies for bait and for human consumption (fresh or canned). The laws passed by the state legislature comprise the Fish and Game Code.

The California Fish and Game Commission is a panel of five people appointed by the Governor. The Commission's main purpose is to determine sportfishing and hunting regulations, which comprise "Title 14." At times, the legislature has voted to give the Commission management authority over certain commercial fisheries. In 1965, the Commission was given such authority to regulate the anchovy reduction fishery.

The Department of Fish and Game is responsible for enforcing the regulations set by both management authorities, which also includes monitoring of the fishery for quota purposes. The Department is a principal source of management advice to the legislature and to the Commission, and usually is the source of draft legislation on fishery matters.

With the enactment of the Fishery Conservation and Management Act of 1976, California State Legislature passed into law (section 7650-3 of Fish and Game Code) a procedure by which the Director of Fish and Game can bring state law or Commission regulations into conformity with fishery management plans prepared by the Pacific Fishery Management Council and approved by the Secretary of Commerce. This law gives the Director the power to make inoperative any statute or regulation for up to 180 days and/or adopt new regulations effective for up to 180 days. The Director must then report such actions to the California State Legislature that need to be enacted as statutes to conform state law to the fishery management plan.

3.3.1.2. International

A new Fisheries Agreement between the United States of America and Mexico that recognizes Mexico's 200 mile Exclusive Economic Zone and the U.S. 200 mile Fishery Conservation Zone was signed November 24, 1976. This agreement does not address bilateral management of the anchovy resource shared by the two nations. It does acknowledge that ". . . the Government of Mexico will promote the objective of optimum utilization of living resources in the Zone off the coast of Mexico . . ."

Article XI states that the two governments ". . . shall consult at least annually with a view to coordinating their respective national management programs and exchanging relevant information and data, in order to promote the effective conservation and optimum utilization of stocks that occur within the zones, and are harvested by their fishermen off their respective coasts." It is further stated in Article XIV that the two governments ". . . will promote cooperation in scientific research that will contribute to the effective conservation and optimum utilization of living resources of mutual interest." Annual consultations on the application and implementation of this agreement will be held in April of each year. Figure 3.3-1 is a map of the agreed boundary.

3.3.2. Outline of current regulatory measures

The following outline is taken from appropriate sections of the California Fish and Game Code regarding take of anchovies and more general area and gear restrictions, and from Title 14 of the California Fish and Game Commission. These regulations are presented in full in Appendix III.

Fishing Seasons: Anchovies may be taken for purposes of reduction between August 1 and May 15 north of Pt. Buchon, and between September 15 and May 15 south of Pt. Buchon. Anchovies may be taken for other purposes, including live or dead-bait, and human consumption, at any time.

Area Closures: Anchovies may not be taken for reduction within 3 miles of the mainland south of Pt. Buchon, or within 3 miles of the northeast side of Santa Catalina Island. There are five local closure areas, including the Gulf of the Farallons, Oxnard, Santa Monica Bay, Los Angeles Harbor and Orange County, and from Oceanside south (see Figure 8.3-1 and Section 8.3.2).

Size Restrictions: There is a 5" total length minimum size limit except for use as live bait. There is a 15% by weight incidental catch allowance, with prescribed methods of sampling to determine if a violation has occurred.

Harvest quota: The quota for the season is to be equal to one-third of the spawning biomass in excess of one million tons, not to exceed 450,000 tons. A determination of spawning biomass must be made in order to implement the formula. The current status of this regulation is discussed in the following section.

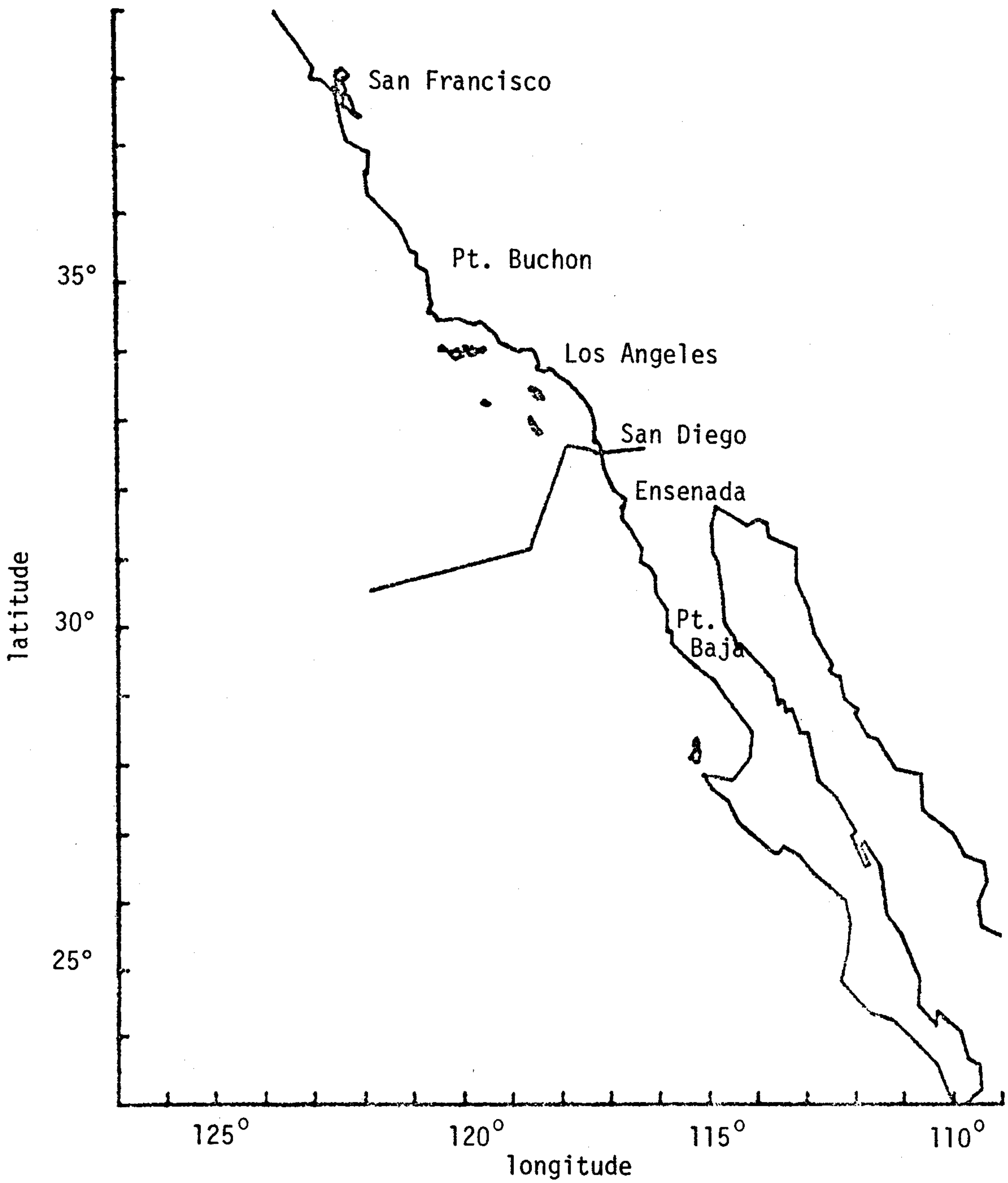

Figure 3.3-1. Agreed 200 mile boundary between U.S. and Mexico

3.3.3 Effectiveness of management measures

The California harvest quota formula was adopted by the Fish and Game Commission in early 1977 and has not been implemented due to the lack of a spawning biomass estimate in 1977. The previous management regime, which continued through the 1977/1978 fishing season, generally allowed a 100 thousand ton quota with extensions being considered later in the season. Current status of total harvest has been monitored by the California Department of Fish and Game, and there has been no difficulty in achieving timely closure of the season when the quota is reached.

Fishing seasons and area closures have generally been aimed at reducing conflict, both physical and psychological, between the reduction fishery and the recreational and live-bait fisheries. The extent to which this has been achieved cannot be determined. The season has been easily enforced, but area closures have caused some difficulties. Early attempts at creating geographic quota zones were abandoned as unenforceable. More recently, some vessels were landing anchovies in southern California between August 1 and September 15 under the pretense that they had been caught legally in waters north of Pt. Conception which was the original boundary of the northern and southern fishery zones. Again, enforcement was unable to counter this ruse, but revision of the regulations (moving the boundary to Pt. Buchon) was sufficient to prevent further occurrences. The present local area closures have not been easily enforced, but sufficient compliance has been achieved.

The minimum size limit has worked well. Fishermen generally prefer larger fish if they are available, so conditions where the minimum size is an issue rarely arise.

In evaluating the overall effectiveness of the California management regime, two considerations must be borne in mind. First, the present quota formula, which is aimed at providing optimum yield from the resource, has not been in effect very long. Secondly, the previous California management regime was operating under quite a different management philosophy. The previous management was intended simply to allow a reasonable fishery while preserving the resource for its uses as predator forage and live bait to the largest extent consistent with the above fishery. This intention was met by the earlier management. The new California plan reflects broader considerations.

3.4. History of Research

3.4.1. Domestic Research

Research on the population of northern anchovy is relatively recent. In general, it began as studies incidental to sardine research in the early 1950's. As sardines disappeared and anchovies became more abundant, research in the pelagic fish stocks took on multiple species objectives. The research of California Department of Fish and Game (CF&G), National Marine Fisheries Service (NMFS), Scripps Institution of Oceanography (SIO) and California Academy of Science has been coordinated through California Cooperative Oceanic Fisheries Investigations (CalCOFI). The CalCOFI research lead to the hypothesis that the expanding anchovy population filled the void in the ecological niche once occupied by the sardine. A fishing experiment was planned that proposed to reduce the anchovy stocks by harvesting 200,000 tons annually so that the sardine might have a chance to return (Hewitt, MS, p. 10). The experiment was never successfully carried out, but the anchovy reduction fishery did begin in the fall of 1965.

NMFS (then the Bureau of Commercial Fisheries) conducted egg and larva surveys in the California Current region beginning in 1949. Anchovy biomass information is available for 1951 to present. In the early 1960's, NMFS initiated physiological research on anchovies that has developed into a thorough investigation of the parameters of the stock-recruitment process. The logbook system for aerial fish spotters that scout for the purse seiners was initiated in 1962. CF&G has conducted sea surveys for mapping the distribution and density of adult fish throughout the year, also since the early 1950's to the present. Once the anchovy reduction fishery began in 1965, CF&G instigated a logbook system and stepped up their catch sampling program, both of which are ongoing. Little has been done with the logbook data with respect to catch per effort information. CF&G has developed ageing methods using scales and otoliths. Age compositions of the samples from sea surveys and port sampling are routinely published. Rates of growth and mortality have subsequently been estimated using this age composition data. With the development of underwater acoustic technology, both CF&G and NMFS developed sonar surveys. CF&G objective was to assess anchovy biomass available to the fishery in the Southern California Bight. NMFS emphasized research and development of technology for assessing pelagic fish stocks. A major tagging program was initiated in the mid-1960's that provided information on fish movement but was terminated.

SIO has emphasized research on the oceanography of the California Current to describe the environment of the pelagic fishery resources. They also have compiled a 2000 year time series on relative biomass of sardine and anchovy from scale deposits in the bottom sediments of anaerobic deep-sea basins.

Identification of possible subpopulations in the anchovy population has been studied by all three agencies since 1950. California Academy of Science supported the coordinator of CalCOFI programs. Their research has emphasized population dynamics of the sardine population and food habits of the various pelagic species.

3.4.2. Foreign Research

The Soviet Union has been interested in the anchovy resource off California since it began its fishery for Pacific hake (Merluccius productus) in 1966. In cooperation with NMFS they have conducted egg and larva surveys particularly directed at Pacific hake. They also have studied the fishery resources using acoustic and midwater trawl surveys. From this research they have attempted to map the density and distribution of the anchovy resources although their results are incomplete because of the limited number of surveys both within a season and between years. They have expressed an interest in developing a commercial fishery for anchovies, but this has never been attempted.

Partially as a result of the well-documented U.S. research on the magnitude of northern anchovy resource off the state of California and Baja California, Mexico, with FAO sponsorship, developed plans for expanding its anchovy fishery in the mid-1970's. Increased research priorities in Mexico have resulted in U.S.-Mexico cooperative research studies and information exchanges. This work is informally coordinated through CalCOFI under the INP-CalCOFI Stock Assessment Committee which meets approximately twice a year. This is a forum for discussing (at the scientific level) research objectives, national fishery objectives and future management policies.

3.5. Socio-Economic Characteristics

Salient economic characteristics of the anchovy fisheries of California are discussed with respect to the commercial fleets landing anchovies and the live-bait fleet selling fish to recreational fishermen and commercial partyboat operators. More detailed treatment of the fishery industrial products markets is presented in Appendix VI. Little comprehensive economic data is available with respect to the live-bait fishery or the recreational fisheries occurring in California. Nevertheless, the social and economic importance of the recreational sector is reflected in the data and descriptive material presented below.

3.5.1. Output of Domestic Fishery

During the period 1970 through 1975, the annual landings of anchovies for reduction purposes averaged 94,815 short tons, while the average reported take for live-bait was 5,997 short tons. Miscellaneous uses for northern anchovy in California accounted for an average of 2,538 short tons of fish per year. As indicated in Tables 3.5-1 and 3.5-2, the landings are heavily concentrated in the Los Angeles (San Pedro) and Santa Barbara (Port Hueneme) areas.

Table 3.5-1. Anchovy Landings by Geographical Areas, 1970-1975.

Year	San Francisco	Monterey	Santa Barbara	Los Angeles	San Diego	Total
	(short tons)					
1970	109	954	9,807	85,373	0	96,242
1971	159	1,205	9,861	33,628	.2	44,852
1972	180	594	13,738	54,587	.7	69,101
1973	398	4,068	16,714	111,485	.1	132,637
1974	420	5,069	18,032	59,195	1	82,717
1975*	429	7,125	25,437	125,519	.2	158,510

(Source: CF&G California Marine Fish Landings for 1970 through 1974.)

*Preliminary CF&G Circular, No. 50.

Table 3.5-2. Value of Anchovy Landings by Geographical Areas, 1970-1975.

Year	San Francisco	Monterey	Santa Barbara	Los Angeles	San Diego	Total
	(thousands of dollars)					
1970	22	33	225	1,877	0	2,157
1971	35	30	268	760	-	1,093
1972	29	24	364	1,260	-	1,678
1973	67	219	859	5,500	-	6,646
1974	73	208	700	2,450	-	3,432
1975*	75	214	763	3,766	-	4,818

(Source: CF&G California Marine Fish Landings for 1970 through 1974.)

*Preliminary estimates based on 1974 average price in San Francisco and $30/ton for fish landed in Monterey through San Diego.

3.5.1.1. Value of Catch

The landings monitored by CF&G (not including bait catches) had an estimated exvessel value of $4,818,000 in 1975, the last year for which official landings figures have been published. The preponderance of this value (about 98 percent) accrues from the landings for reduction. In response to domestic and world markets for fish meal and other protein meals, the exvessel price of anchovy varies considerably. By agreement between the Fishermen's Cooperative Association of San Pedro and major buyers of anchovy for reduction, the exvessel price is tied directly to the established market price for protein. The current arrangement calls for a minimum price of 25 dollars per ton of anchovy when the price of protein is 3 dollars or less per unit. (The price per unit of protein equals the price per ton of meal divided by 65). Each additional 10 cent increase in the unit price of protein calls for a 75 cent increase in the exvessel price of anchovies.

As a result of the pricing arrangements and the great variability exhibited by protein meal markets, it can be expected that anchovy exvessel prices will continue to fluctuate. In future price variations, an important role will be played by the Peruvian anchoveta fishery. A flood of new fish meal production from Peru could easily dampen the domestic market prices for anchovy and for domestic fish meal generally. Expanding world demand for fish protein may, however, divert most Peruvian meal to other nations.

The value of live-bait catches are not routinely monitored by official agencies. Nevertheless, a rough estimate of value can be made. Bait haulers generally operate on contract with commercial partyboat operators. As a rough average, the partyboats pay 15 percent of the revenue from passenger receipts in return for a live-bait supply equal to 1/2 scoop per angler. According to CF&G (see CF&G Anchovy Plan, p.111), there were 748,052 partyboats anglers in 1975 paying a rough average of 15 dollars per trip. This yields a gross revenue of 11.2 million dollars. About 68 percent of this revenue would be earned by southern California partyboats which utilize live bait extensively. If live-bait dealers receive 15 percent of the partyboat revenue, then a total of 1.15 million dollars would be paid for bait. In addition to the revenue from bait delivered to partyboats, revenue is generated by sale to private vessels. Generally the private vessels buy anchovies by the "scoop" at bait holding facilities at an estimated price of $5 for a scoop containing 8 to 10 pounds. According to industry sources, the bait sales to private vessels account for approximately 50 percent of total sales. Thus the total value of anchovy bait catches would average about 2.29 million dollars. Although the value calculated in this fashion is only an approximation, it does indicate that the economic value of live bait is far greater than the volume of catch would suggest.

3.5.1.2. Description and Value of Products

The major uses for anchovy are for fishery industrial products and for bait, while minor portions of the annual harvest go into such products as fresh fish for human consumption, canned fish for human consumption, canned anchovy paste, and frozen bait. At present, the fishery industrial products consume most of the anchovy landings, and are likely to continue to do so. These products consist of meal, oil and solubles. The meal produced from anchovies is generally 65% protein. The oil and residual liquids are separated and the oil sold in competition with other similar oils. The residual liquid is evaporated to produce a 40 percent solution containing about 30 percent protein and is sold as fish solubles.

The market prices for the three products of the reduction fishery in 1976 averaged $289 per ton for meal, 14 cents per pound for oil, and $110 per ton for solubles. The total value of all industrial anchovy products is estimated at $8,412,000 for 1976 (see table 3.5-3. for other years).

Table 3.5-3. Industrial Products from Anchovies.

Year	Meal (tons)	Value ($1000's)	Oil 1,000 lbs	Value ($1000's)	Solubles[3] (tons)	Value ($1000's)
1976	21,968	$6,353[1]	5,184	$ 726[2]	12,118	$1,333[4]
1975	27,704	$6,559	12,857	$1,547	17,271	
1974	14,058	$4,189	5,602	$ 835	9,061	
1973	22,039	$8,879	10,549	$1,180	14,621	
1972	11,134	$1,892	4,372	$ 234	7,461	
1971	7,718	$1,195	3,169	$ 176	4,889	
1970	16,200	$2,787	6,165	$ 439	10,411	
1969	11,436	$1,738	4,862	$ 207	6,967	
1968	2,762	$ 337	899	$ 32	1,545	
1967	5,575	$ 722	1,004	$ 39	3,623	
1966	4,468	$ 676	773	$ 57	3,063	

[1] Based on average monthly price per unit protein through October ($289.2 per ton of meal = 4.45/unit)

[2] Based on oil prices through October as reported in NMFS, Industrial Fishery Products, Current Economic Analysis I-28. Nov. 1976.

[3] Solubles are not reported for anchovies specifically. These figures are based upon the rule-of-thumb that the yield of solubles equals 11.2 percent of raw anchovy input.

[4] Approximation based on price of 110 dollars per ton from NMFS Fishery Market News Reports, in 1976.

3.5.1.3. Markets, Domestic and Export

The domestic market for anchovy meal is the widely distributed animal feed mix business. All fish meals, including tuna, menhaden, herring and imported Peruvian anchovy meals, contain high levels of proteins with well-balanced amino acid content. This amino acid balance, as well as some trace minerals and other nutritive factors, are highly desirable components in poultry feed, hog feed, and fish feed. Much of the meal produced in California is sold to poultry growers in the state; but the market can extend as far east as Arkansas, depending upon the price and availability of competitive meals. Also, anchovy meal is used in preparing feed mixes for various freshwater fish, including trout and salmon raised in hatcheries.

Fish solubles can be returned to the fish meal to create a product known as whole meal. The process requires substantial additional drying by the producers. Such drying is not only expensive, but causes additional air pollution control problems for the producer. As a result, most of the solubles from California anchovy reduction plants is sold directly in liquid form. The liquid can be sprayed and mixed into feed mixes as an additional supplement having nutritional value similar to that of meal itself.

The poultry industry in California which absorbs much of the locally produced meal and solubles is a substantial portion of the state's agricultural complex. California is the leading state in production of chicken eggs, and is the second leading state in production of turkeys. When feed mixers cannot obtain desired quantities of high protein fish meals, the dietary requirements can be met for the most part by substitution of vegetable protein products, such as soybean meal, or of meals made from meat by-products. Some nutritionists express a preference for fish meal due to high concentration of the amino acids lysine and methionine and to the presence of other growth factors. Analysis of the nutritional elements indicates that the previously "unidentified growth factor" in fish meal is a combination of trace minerals, B vitamins, and well-balanced amino acid complex. Whether or not fish meal is essential to the feeding of poultry stock, it is superior to vegetable proteins in that a smaller volume of fish meal carries a more concentrated load of protein and other nutritional elements.

Fish oil is utilized domestically in paints and lubricants, while export markets in Europe channel fish oil into human consumable items, such as margarine, as well as into other industrial uses. The oil content of anchovies influences directly the output of oil from the reduction plants. To the extent that oil yields from anchovy reduction vary, so must the revenue earned by processors per ton of anchovy.

The preponderance of the domestic market for fish meal is supplied with menhaden and imported (primarily Peruvian) meal. Tuna (or tuna/mackerel) meal is produced by all major tuna canneries in California and Puerto Rico. Menhaden meal originates from the Atlantic and Gulf Coasts. Because of shipping costs, the menhaden meal is generally not sold in California, while the anchovy meal produced in California is not sold in the eastern portion of the United States. Nevertheless, the boundaries of the markets are fluid with market prices and supplies having a controlling influence on the extent to which a batch of meal will be shipped inter-regionally.

Because the output of anchovy reduction plants in California is small in comparison to that of the domestic menhaden industry and to that of the foreign fish meal industries, the prices paid for domestic anchovy meal are at the mercy of a dominant national and worldwide market. The success or failure of U.S. soybean crops and Peruvian anchovy harvest will have a controlling influence on the domestic demand for California anchovy meal. The price of anchovy meal is determined in a highly competitive market for high protein oil cake meals and is little influenced by the domestic production of anchovy meal itself. The statistical analysis of demand for fish meal incorporated in Appendix VI lends support to these statements. The analysis in Appendix VI indicates also that the market for fish meal from California is sufficiently isolated by geographical distance and transport costs from the East and Gulf Coast supplies of fish meal that prices in California can move somewhat independently from national average prices.

3.5.2. Domestic commercial fleet characteristics

From an economic standpoint there is no unified "anchovy fishing fleet." The fleet can be usefully divided into four segments: 1) the wetfish vessels, 2) combination vessels, 3) live-bait vessels, and 4) miscellaneous smaller round haul boats (see Table 3.5.-4). The wetfish vessels are relatively small purse seiners varying in length from slightly less than thirty feet to more than eighty feet, and in net registered tonnage from about thirty to nearly one hundred tons. The number of wetfish vessels varies from year to year. The numbers reported landing anchovies during 1973, 1974 and 1975 were 26, 28 and 30. During these same three years, the wetfish vessels accounted for 68 percent of all anchovy landings in California (not including live-bait catches).

Combination vessels are similar to wetfish vessels, but are generally larger (80 to 150 net registered tons). They typically fish for bluefin, yellowfin and skipjack tuna during part of the year, while fishing for anchovy is more of a sideline. Nevertheless, the superior fishing power of the larger vessels allows them to harvest significant quantities. During 1973-75, while no more than seven combination vessels were landing anchovies in any one year, they accounted for slightly more than twenty percent of the total anchovies landed.

Table 3.5.-4. Anchovy Harvests by Wetfish Vessels, Combination Vessels, Live-Bait Vessels and Others.

	1973	1974	1975
Wetfish: Catch (tons)	87,418	53,995	111,342
Number	26	28	30
Combination: Catch	27,580	17,900	31,357
Number	7	7	4
Live-Bait: Catch	5,944	6,318	5,370
Number	11	14	12
Other: Catch	17,592	10,819	15,764
Number	36	39	36

Live-bait vessels are generally in the same size range as the wetfish vessels, but use lampara, rather than purse seine nets to capture anchovies. If a vessel holds a reduction fishery permit, it may deliver some of its anchovy harvests to reduction plants. The California Department of Fish and Game landings records indicate that some small portion of the live-bait vessels' catch is landed for reduction or other purposes. Normally, the catch of anchovies for live bait is not considered a "landing" and is not recorded by the landings receipt system of CF&G. A voluntary reporting system is participated in by most live-bait fishermen, and results in the live-bait fishery statistics presented above (Table 3.2-3). In recent years, the number of vessels in the live-bait fishery has been around twelve to fourteen.

The group of smaller round haul vessels numbers between thirty-five and forty. This group includes the fleet of lampara vessels fishing for reduction plants in the Monterey area, a few small purse seiners from the Pacific Northwest which enter the California anchovy reduction fishery occasionally, and other vessels landing anchovies in relatively small quantities for canning, frozen bait, fresh market or other species. During the 1973-75 period, this miscellaneous fleet accounted for about 12 percent of the landings of anchovies in California.

3.5.2.1. Income earned from the fishery

The total revenue from sale of anchovies exvessel has been discussed in section 3.5.1.1, but some additional characteristics of the commercial value are of interest. The income earned from anchovy fishing is clearly unevenly distributed among vessels, and it is highly variable during the year. Also, most vessels earn income from sales of other pelagic schooling fish that can be caught by purse seining.

The uneveness of catch distribution is depicted in Figure 3.5.-1. The upper panel is a histogram showing the number of vessels falling within annual landings classes from 0 to 1000 tons, 1000 to 2000 tons and so forth. The data are for 1975. Assuming that the amount of income earned is roughly proportional to the amount of fish landed, the figure indicates that there are many vessels earning little from the anchovy fishery and there are a few vessels earning considerable sums. At 1976 prices, for instance, a 1000 ton catch would be worth about 35,000 dollars while an 8,000 ton catch would be worth about 280,000 dollars. While the average landing per vessel was only 2,264 in 1975, the landings as a whole were dominated by the vessels landing large quantities. The lower panel in Figure 3.5.-1 is a Lorenz curve showing the degree of inequality in the distribution of anchovy landings. The Lorenz curve shows the percent of total landings taken (vertical axis) by successively larger segments of the fleet (horizontal axis). The 50 percent of the fleet having the smallest landings, for instance, caught only about 5 percent of the year's landings. The top 10 percent of the vessels caught nearly 40 percent of the landings. Thus, the bulk of the fleet derives relatively little income from the anchovy fishery.

Histogram. Number of vessels = 70

Average catch per vessel = 2264 tons

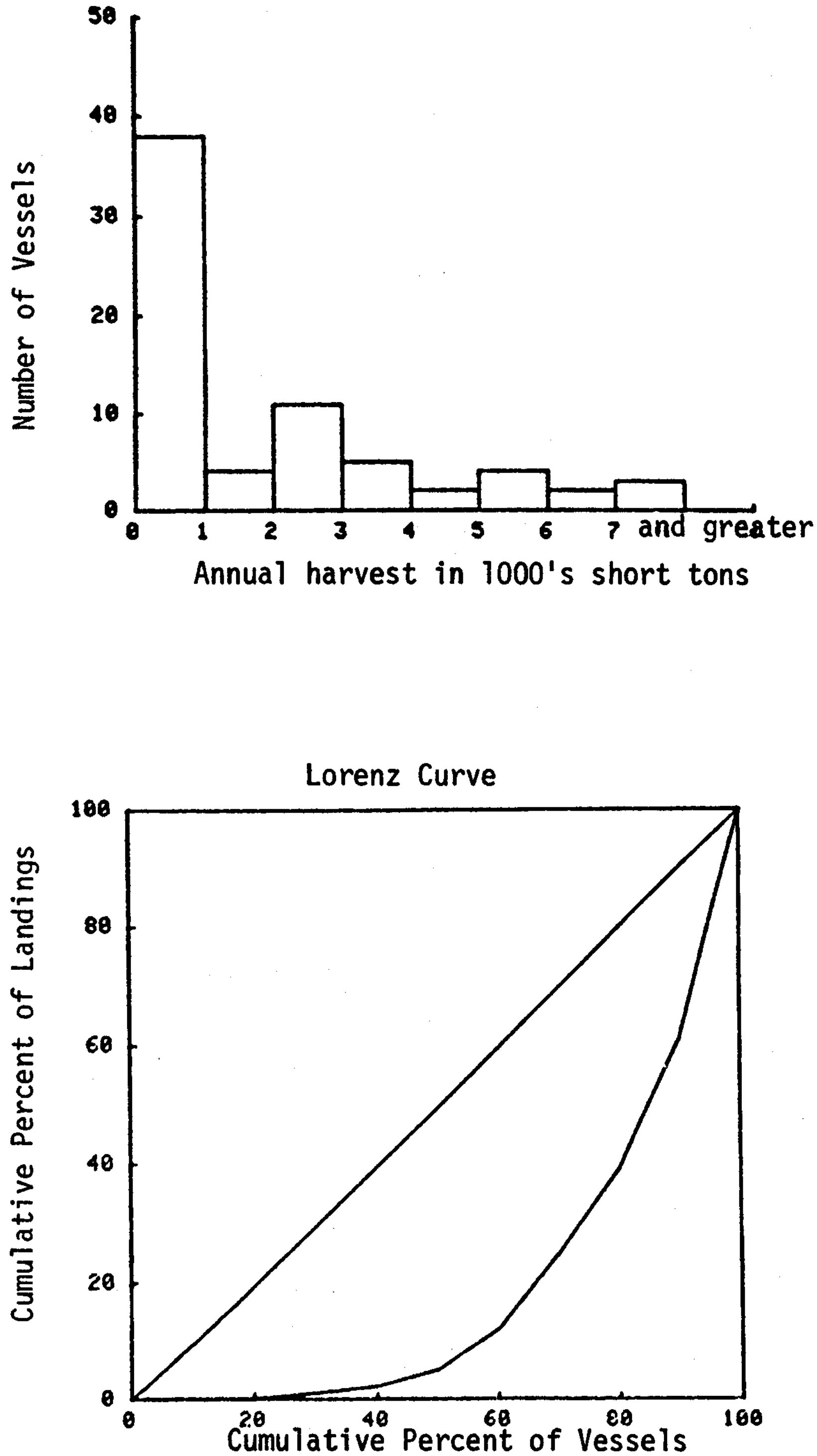

Figure 3.5.-1. Distribution of anchovy landings among vessels, 1975.

The variability of the anchovy reduction fishery is illustrated in Figure 3.5.-2. Several factors contribute to the extreme variability of the weekly landings. High winds, waves or a bright moon create difficult conditions for the fishers; and the reduction fishery often halts entirely when conditions are poor. At other times, for instance weeks 21 through 24 of the 1976/77 season, the fish are not sufficiently concentrated in surface schools to allow good fishing. This can happen even when other conditions are excellent. Also, some of the reduction plants may occasionally reduce or completely eliminate their orders for anchovies, because large quantities of tuna and mackerel scrap are being reduced.

Live-bait vessels generally derive the vast preponderance of their incomes from the harvest of anchovies. This is not necessarily the case with the other anchovy fishing vessels. Some vessels concentrate on the anchovy reduction fishery while others participate casually or incidentally. This is one reason for the highly skewed distribution of annual harvests depicted in Figure 3.5-1. The wetfish vessels, which dominate the anchovy reduction fishery, harvest substantial quantities of jack mackerel, bonito, and squid. Many of the wetfish vessels in the past harvested sardines, Pacific mackerel and yellowtail. Currently the sardine stock is severely depleted and the state of California prohibits commercial fisheries directed against them. The depressed Pacific mackerel stock has shown an encouraging increase in recent years. Under a California management law which prescribes variable quotas based on spawning biomass, a 1500 ton harvest was set for 1977, much of which was caught incidentally to the jack mackerel fishery. Commercial yellowtail fishing has been minimal since the late 1950's. Larger wetfish vessels and combination vessels harvest tunas during the spring and summer. Table 3.5-5 indicates the degree of participation of anchovy fishing vessels (not including live-bait vessels) in three of the more important southern California pelagic fisheries. Most of the vessels catching jack mackerel and bonito in quantities greater than 25 tons are wetfish vessels, while most of those catching bluefin tuna in quantities greater than 25 tons could be classified as combination vessels.

The revenue derived from anchovy, jack mackerel, bonito and bluefin tuna harvests by the anchovy fishing vessels is given in Table 3.5-6. The importance of anchovy harvests is apparent. Also apparent is the increasing importance of jack mackerel, and the dwindling importance of bonito harvests. The latter results from depletion of the Pacific bonito stocks off southern California (see MacCall, Stauffer and Troadec, 1976 and Collins and MacCall, 1977). Generally, the southern California wetfish fleet is dependent on the anchovy fishery for its economic survival. This was not always the case. And in view of the fleet's history as an opportunistic, multi-species fishing fleet, the resurgence of sardines, bonito or Pacific mackerel could turn the fleet's attention toward other species. The 1977 harvest of jack mackerel may show a threefold increase over recent harvest levels, and further expansion of this fishery is likely to divert effort from anchovy fishing.

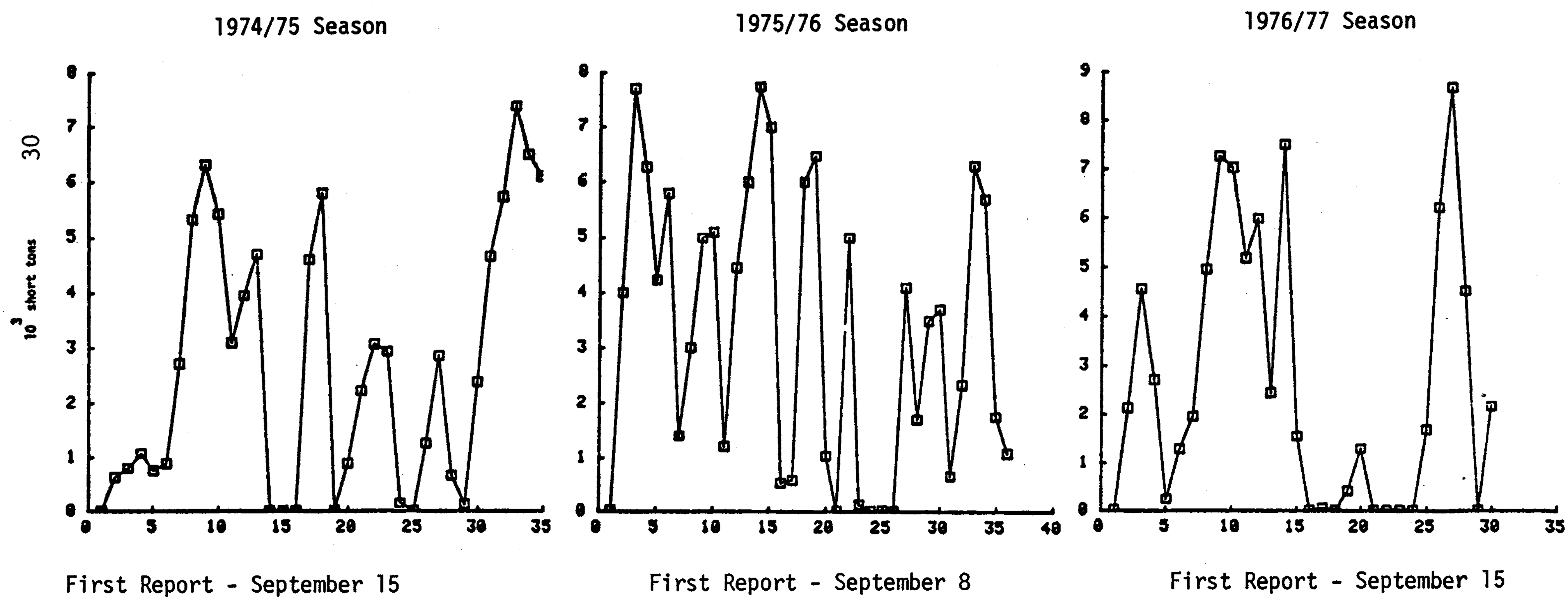

Figure 3.5.-2. Anchovy reduction fishery weekly landings.

Table 3.5-5. Participation of anchovy fishery vessels in the jack mackerel, bonito and bluefin tuna fisheries.

	1973	1974	1975
Number of Vessels with Anchovy Landings:			
In any amount	69	74	70
Greater than 25 tons	61	59	60
Number Landing Jack Mackerel:			
In any amount	45	42	38
Greater than 25 tons	28	25	28
Number Landing Bonito:			
In any amount	41	34	25
Greater than 25 tons	35	29	14
Number Landing Bluefin Tuna:			
In any amount	22	29	27
Greater than 25 tons	14	20	21

Table 3.5-6. Catch and Revenue of Four Major Species Caught by Anchovy Vessels, 1973-1975.

Catch:	1973	1974 (short tons)	1975
Jack mackerel	10,000	12,503	16,829
Bonito	9,527	5,798	1,872
Bluefin tuna	1,650	2,157	2,400
Anchovy	132,636	82,717	158,511
TOTAL	153,813	103,175	179,612
Revenue		($1000's)	
Jack mackerel	962	1,470	1,526
Bonito	1,982	1,548	525
Bluefin tuna	772	1,225	1,153
Anchovy	6,646	3,432	4,790
TOTAL	10,362	7,675	7,994

3.5.2.2. Investments in Fishing Gear

Because public records of the investments specifically in anchovy fishing vessels and gear are non-existent, little is known of this aspect of the fishery. County property tax records give some indication of the value of the fishing vessels, however, and a sample of wetfish vessels demonstrates a wide variance in assessed values. Projected market values (100 times assessed value) run from $70 thousand for some of the smaller, older vessels to as much as $1.8 million for a newer, larger vessel. Without additional information, the capital value of the anchovy fishing fleet cannot be adequately estimated.

3.5.2.3 Manpower Employed

Just as the number of vessels participating in the fishery varies, so does the number of fishermen. For any given year, the number of fishermen involved in anchovy fishing can be estimated by adding up the number of crew members for each participating vessel as indicated in CF&G's vessel registration file. For 1975 there were an estimated 472 crew members on vessels fishing anchovies, distributed among vessel types as follows: wetfish, 291; combination vessels, 43; others, 138; and bait vessels, about 70. The live-bait vessel crewmen are probably employed nearly year around in anchovy fishing, while the other vessel's crewmen are in varying degrees, part-time anchovy fishermen.

3.5.3. Domestic Commercial Processing

The processing of anchovy into industrial products takes place in three companies at Terminal Island, one company at Oxnard, one company at Salinas and one at Moss Landing. The companies at Terminal Island are all engaged primarily in canning tuna and mackerel, using the reduction plants to produce tuna/mackerel meal. The annual landings of anchovies and the production of industrial products is concentrated in the Terminal Island location. As indicated in Table 3.5-7, the Los Angeles area landings of anchovy account for most of the tonnage and value.

The canning of anchovies in a "sardine-style" pack takes place in the Monterey area. Potentially, many canners in other locations could produce canned anchovies. At prices sufficiently high to cover costs, however, there is currently little domestic demand for canned anchovies. As a result, the annual case pack (5 oz.-100 equivalents) dropped from a high of 1,144,757 in 1953, to an average of 33,000 in the 1960's and an average of 500 in the 1970's.

Gross income from fish reduction plants in California includes revenue from tuna/mackerel meal, oil and solubles. Offal from the tuna canning industry at Terminal Island and San Diego is reduced to meal in quantity exceeding that of the anchovy meal. The two canneries in San Diego produce exclusively tuna meal, but could include anchovy meal in the future if economic and political conditions make it profitable.

The employment directly attributable to the reduction plants is minimal. While no accurate employment figures are available, there are probably about 50 people directly employed at reduction plants in southern California as a result of the anchovy reduction fishery.

3.5.4.1. Seasonal and Geographic Characteristics

Preliminary summaries of partyboat logbook information for the year 1975 are given in Table 3.5-8. Peak fishing activity typically occurs in the months of May through September. A somewhat more detailed view of southern California activity patterns is provided by the six individual reporting areas from Santa Barbara to San Diego (Table 3.5-8a). The Santa Monica and San Diego regions are of similar magnitudes and account for over half the southern California partyboat effort between them. Seasonality is shown by comparing the effort expended during the three peak months of June, July and August, with the three slow months of December, January and February. As a summer/winter ratio (Table 3.5-8a) this measure shows greater seasonal variation for the more southern reporting areas, particularly Oceanside and San Diego. Whereas Santa Monica activity doubles during the summer, San Diego activity increases eight-fold.

Table 3.5-8a. Southern California Regional Partyboat Angler Effort in 1975.

Region	San Diego	Oceanside	Newport	Long Beach	Santa Monica	Santa Barbara	Total
Annual angler trips	136,718	64,853	20,450	81,432	122,042	84,733	510,228
Percent of annual total	27	13	4	16	24	17	
Summer/winter ratio*	8.57	6.33	2.78	3.48	2.10	2.04	3.59

*Summer/winter ratio is (June, July, August)/(January, February, December)

Partyboat logbook information for the year 1970 was summarized by CF&G statistical reporting block (10 minute square), providing a rough indication of the geographic distribution of recreational fishing activity (Figure 3.5-2a). This compilation does not include distant water albacore fishing effort, or long-range trips to Mexico, which account for over 50,000 angler trips annually, and represent trips of much longer duration than local day trips. Most of the angling effort was near the mainland shore from Oxnard south. Considerable amounts of effort were expended around islands, particularly the Coronado Islands, San Clemente and Santa Catalina Islands, and the Channel Islands in the Santa Barbara area (which accounts for most of the Santa Barbara activity). While the reporting grid is too coarse to supply detailed inshore-offshore information, the San Pedro Channel, between Santa Catalina Island and the mainland appears to be heavily fished both inshore and offshore, as is the area between Oxnard, Santa Barbara, and the Channel Islands.

3.5.4.2 Species Composition of Catch

A summary of fish species caught from commercial partyboats in California is presented in Table 3.5-9. Notable patterns in partyboat species composition are (1) the dramatic increase in rockfish catches in recent years, (2) a substantial decrease in catch of barracuda, and (3) an up-and-down pattern in catches of Pacific bonito, albacore and California halibut. Possible reasons for these changes are many. They include (1) water temperature affecting fish distributions, (2) overfishing of sub-tropical species by recreational fishing or commercial fishing or both, (3) habitat degradations (water pollution in the Los Angeles area, loss of kelp beds), and (4) reduction or dispersion of forage fish due to the commercial anchovy reduction fishery. Although insufficient scientific evidence has been compiled to explain observed variations in abundance of recreational fish species in southern California, many recreationalists tend to place substantial weight on the fourth possible cause--the reduction in available forage to attract and nuture gamefish near populated areas in southern California.

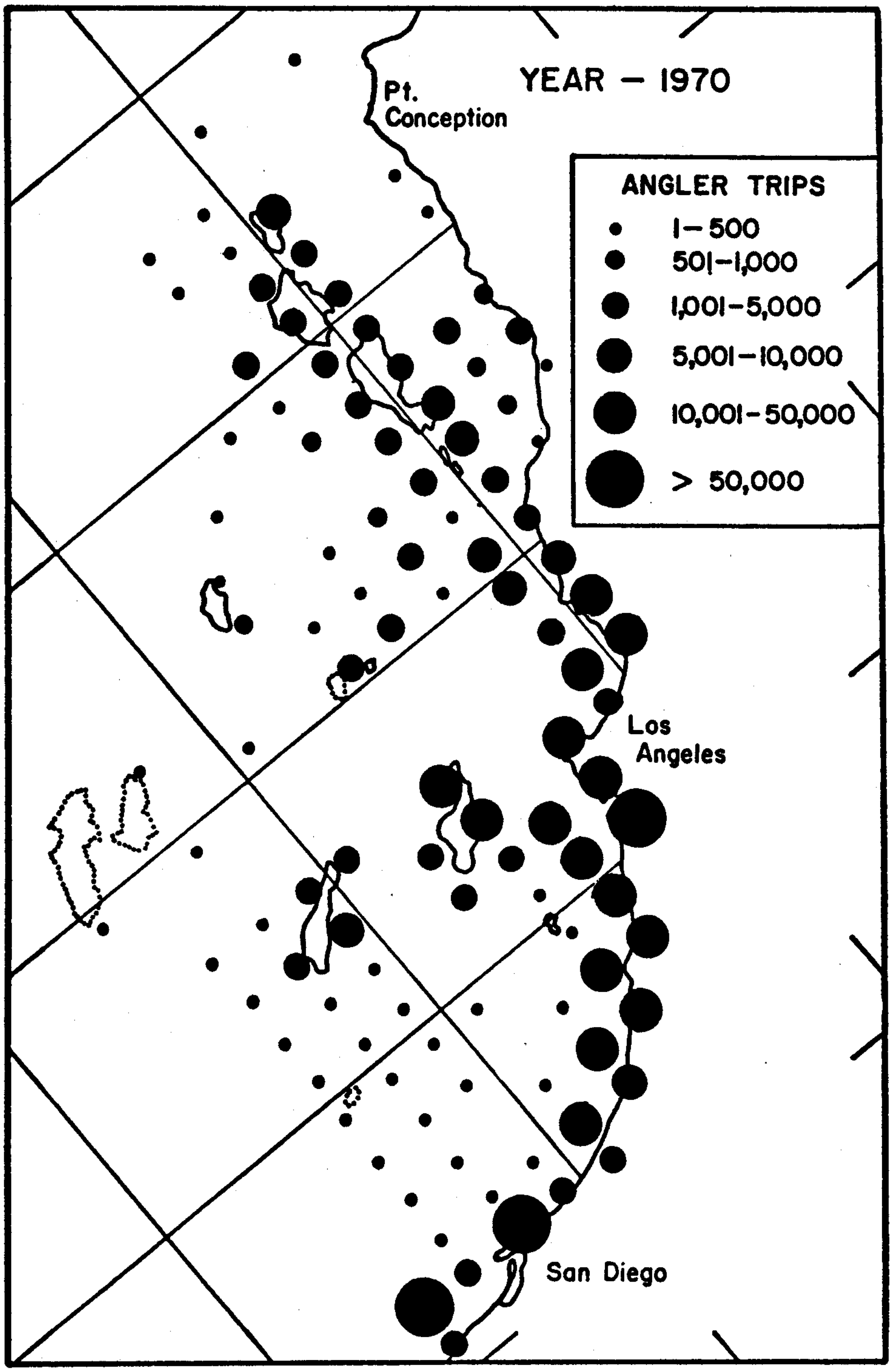

Figure 3.5-2a. Geographical distribution of Southern California Partyboat Angling Effort in 1970.

Table 3.5-8. Monthly Partyboat Catch and Anglers in California, 1975 (1000's).

Month	Southern California		Central and Northern California	
	Number fish	Number anglers	Number fish	Number anglers
January	219.1	22.0	39.0	3.8
February	174.3	17.4	51.1	9.7
March	159.3	18.3	66.1	11.9
April	166.0	19.1	96.8	17.7
May	281.3	37.8	141.1	20.1
June	344.8	49.2	166.5	22.9
July	481.1	78.9	237.3	31.2
August	482.2	87.5	295.3	38.8
September	283.8	40.9	165.6	23.8
October	259.9	29.8	94.3	17.9
November	203.4	21.6	49.5	10.1
December	197.3	20.6	32.1	4.0
Total*	3,769.0	510.2	1,585.0	237.8

*Sum of monthly figures does not equal total figures because monthly figures are preliminary.

Table 3.5-9. Partial* Species Composition of Statewide California Partyboat Catches in Three Historical Periods (average number of fish per year [1000's]).

	1973-75	1963-65	1956-58
Rockfishes	3,844	1,092	1,664
Bass (kelp and sand)	591	1,184	578
Pacific bonito	232	960	248
Pacific mackerel	144	133	137
Yellowtail	121	34	132
Salmon	102	72	71
Sculpin	84	67	21
Lingcod	83	29	385
Barracuda	58	410	483
Sheephead	36	29	16
Albacore	35	124	38
Sablefish	23	5	2
California halibut	10	128	16
White seabass	5	15	24
Bluefin tuna	5	.5	14
Giant seabass	.5	.5	.1

* Not all species reported in partyboat catches are included. Some species appearing to be numerically unimportant (such as halibut, white seabass, bluefin tuna and giant seabass) are included because partyboat operators consider them important. (Young, 1969; p.39).

3.5.4.3. Recreational Catch and the Anchovy Reduction Fishery

Anchovies are an important source of forage for higher level predators as indicated by analysis of stomach contents. To some extent, the apparent importance of anchovies results from its relative abundance rather than from specific feeding habits of predators (Pinkas et al. 1971; Baxter, 1960). Sufficient food chain studies have not been completed for determining the extent to which predators depend upon anchovies as a food supply. Many predator fish appear to be opportunistic, eating any available prey and not targeting on specific prey species.

Recreational fishery spokesmen have been particularly concerned with the impact of a large anchovy fishery in the San Pedro Channel, an area of intense recreational fishing which serves residents of the Los Angeles area (e.g., over 250,000 partyboat anglers/year) (Fig. 3.5-3). An examination of the catch per effort (fish per angler) for the partyboat fishery in the Los Angeles area within the proximity of the commercial anchovy reduction fishery and for the ports from Dana Point to San Diego south of the fishery provides a comparison of availability of the important recreational fish to the partyboat angler before and after the start of the reduction fishery in 1966 (Fig. 3.5-4 and 3.5-5). There has been a trend toward fewer gamefish and more "last choice" species such as rockfish in the catch compositions in recent years for the Los Angeles area. The decline in the availability of bonito to the recreational fishery since the early 1960's has been the result of low recruitment levels of the incoming year classes combined with the intense recreational and particularly commercial fisheries (MacCall et al. 1976, p. 14 and Collins and MacCall 1977, p. 28). The downward trend for bonito is similar for both the southern and Los Angeles areas.

In the case of barracuda which was a depressed stock even prior to the beginning of the reduction fishery, the catch per effort declined considerably in 1971 as the result of a new 28-inch size limit. (MacCall et al 1976, p.9). Since this law, the average size of the partyboat-caught barracuda has been gradually increasing. The availability of yellowtail in the area of the reduction fishery has always been low. (MacCall et al 1976, p.23) (Figure 3.5-5). San Diego has been the major port for yellowtail. The number of fish per angler has only slightly increased since 1973, particularly in San Diego.

The catch rate of the bass group, Paralabrax spp., which is reserved for recreational fishing only, has a slight declining trend in San Diego. (Figure 3.5-4 and 3.5-5). In the Los Angeles area, the catch rate peaked in 1969 and has since declined as the rockfish catch rates increased from two to over six fish per angler. It is quite likely that the decline in bass catch rate is the result of the fishing effort being diverted to rockfish such that the effort is not capable of catching gamefish like the bass, creating a reduction in effort on gamefish.

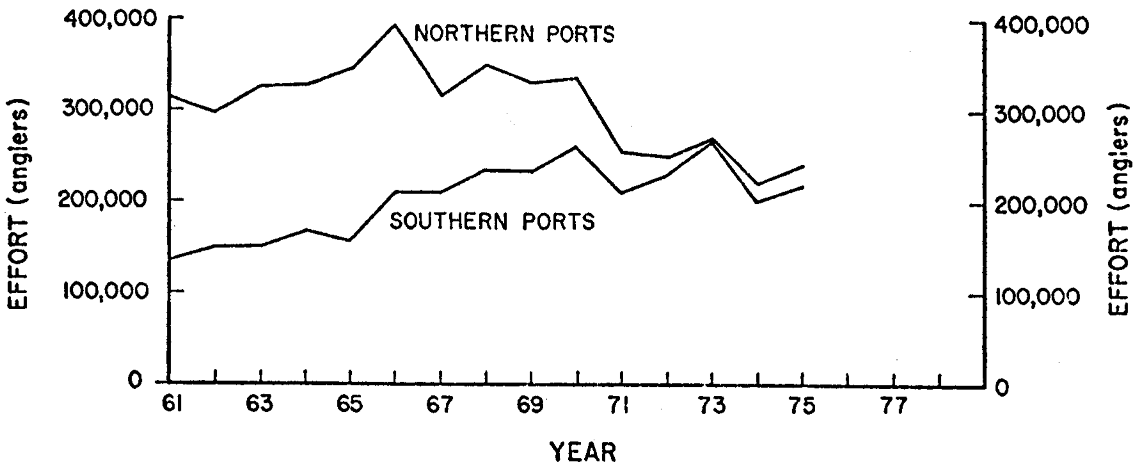

Figure 3.5-3. Annual partyboat effort in angler trips for the Los Angeles area (northern ports) and Oceanside to San Diego (southern ports). Source: CF&G partyboat records.

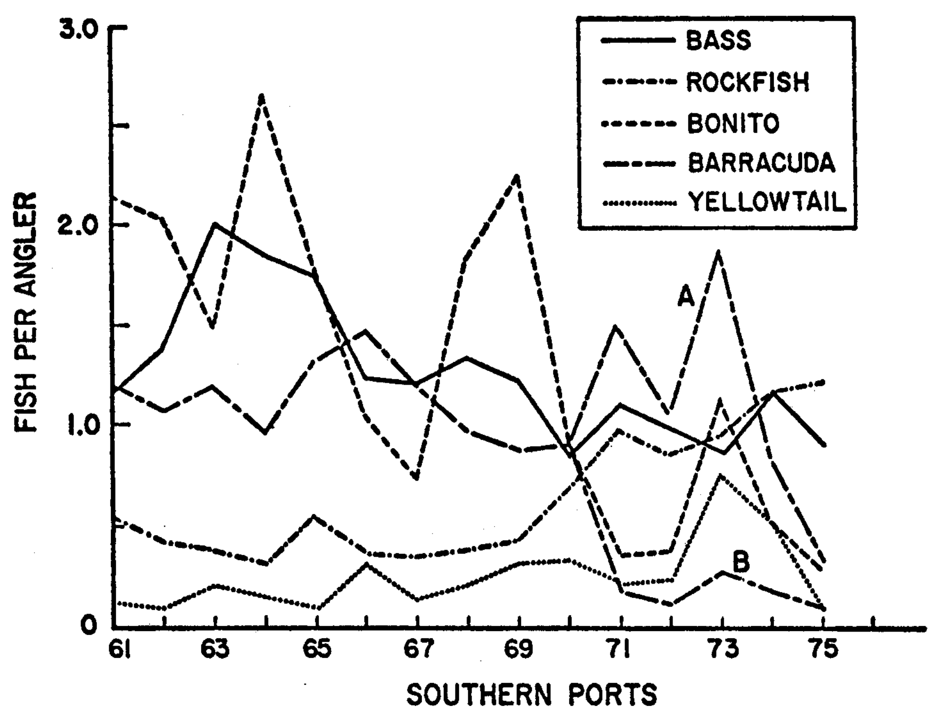

Figure 3.5-4. Annual partyboat catch per effort (fish per angler) for important recreational species for southern ports. Note line A for barracuda is the total C/E including under-sized fish that are released; line B is C/E for the legal size barracuda. Source: CF&G partyboat records.

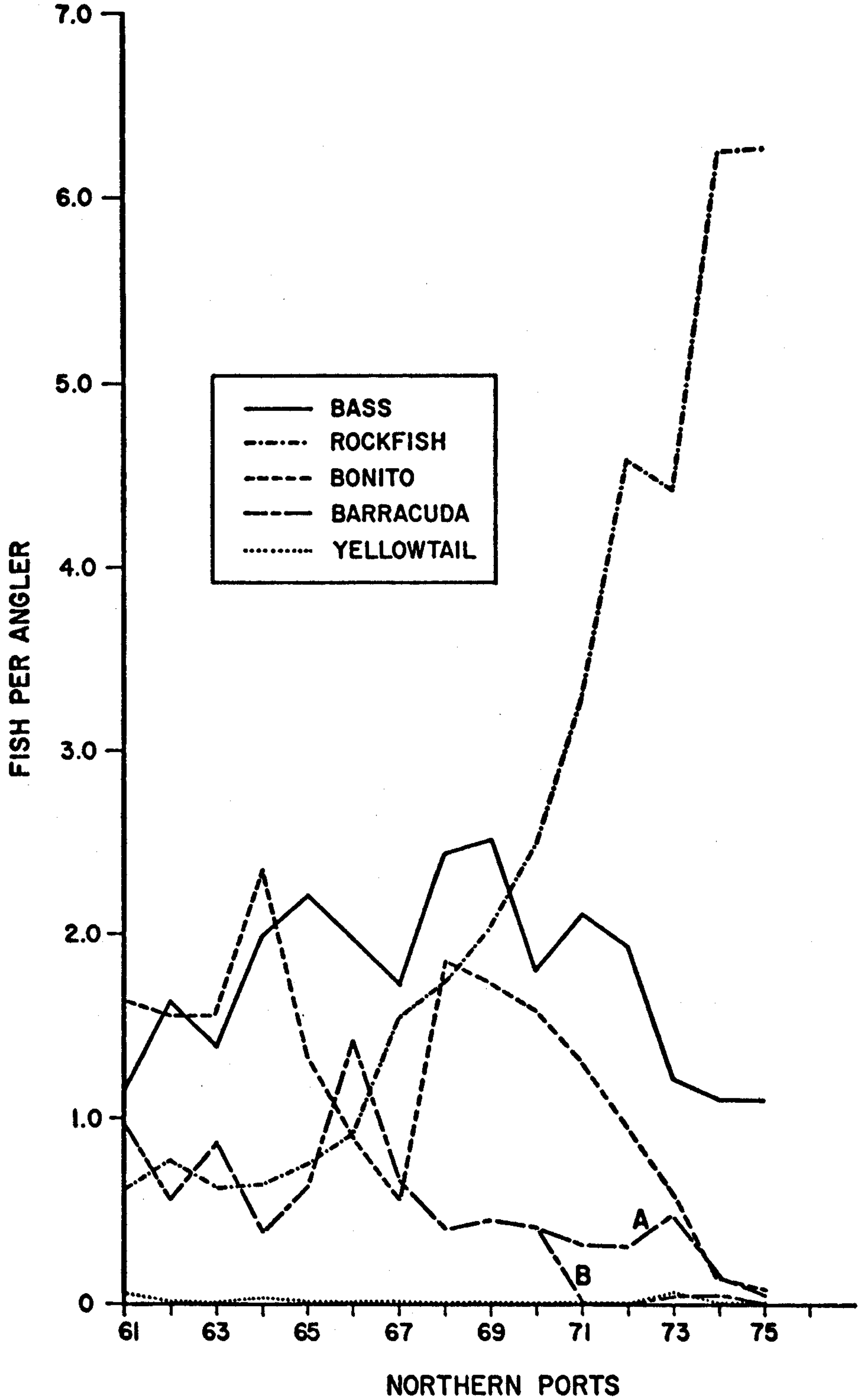

Figure 3.5-5. Annual partyboat catch per effort (fish per angler) for important recreational species for the Los Angeles area. Note line A for barracuda is the total C/E including undersized fish that are released; line B is C/E for the legal size barracuda. Source: CF&G partyboat records.

Even though there is a trend toward fewer of these gamefish in the Los Angeles area in recent years, any relationship between the anchovy resource and its fishery with availability of bonita and barracuda is probably overshadowed by the direct impact of the fisheries for these latter species.

3.5.4.4. Recreational Fishing and Bait Supplies

Vessel-based recreational fishing is highly dependent upon live bait for maintaining high catch rates of gamefish. The live anchovies are used as "chum" to attract fish to the boat, and are also used as a semi free-swimming bait when they are carefully impaled on fish hooks. In the absence of live bait, fishing success tends to drop. Anchovies are not the only live bait used in California, but are the most abundant source of bait. Squid and sardines are used when available, and frozen bait is used at times.

There are occasional periods when live-bait fisheries are unable to find bait within the normal range of operations (about a 50-mile radius). Live-bait holding pens help to fill in during short periods of poor availability, but the limited holding capacity of the pens and the limited life-span of captive anchovies prevent the retention of more than about a one-week supply of bait.

Because lampara nets are used, which require a shallow sea-bottom to work effectively, live-bait fishing operations occur in the inshore areas rather than offshore in deeper water. The reduction fishery, utilizing purse seine gear, takes place in deeper water. To some extent, therefore, the bait fishing operation is more sensitive to distributional charges in the anchovy stocks than is the reduction fishery.

Bait fishermen often contend that their difficulties in finding bait are due to the reduction fishery. According to bait fishermen, the normal behavior of anchovy schools causes large offshore schools to "break up" into smaller schools which move inshore where they are then available as bait. The reduction fishery causes this "breaking up" to be less frequent, thus lowering the abundance of catchable bait. Also, it is contended, the fish that do enter the baiting grounds tend to be "spooky" and hard to catch due to the harassment of the reduction fishery purse seining operations. MacCall et al. (1976, p. 25-27) examined the catch and effort data from the live-bait fishery logbooks for the years 1960 to 1972. These records are voluntarily submitted to CF&G. Their analysis has not been updated to include the recent 4 years. They found that the long-term trends in catch per effort in scoops per trip for the San Diego and Los Angeles regions has been toward an increase in availability of anchovies to the bait fishery (Fig. 3.5-6). The Santa Barbara region appeared to have experienced a slight increase in availability up to 1969 but then suffered a decline in 1970, 1971 and 1972. They further examined the ratio of winter to summer catch per effort for short-term changes in anchovy bait availability for reduction and non-reduction years.

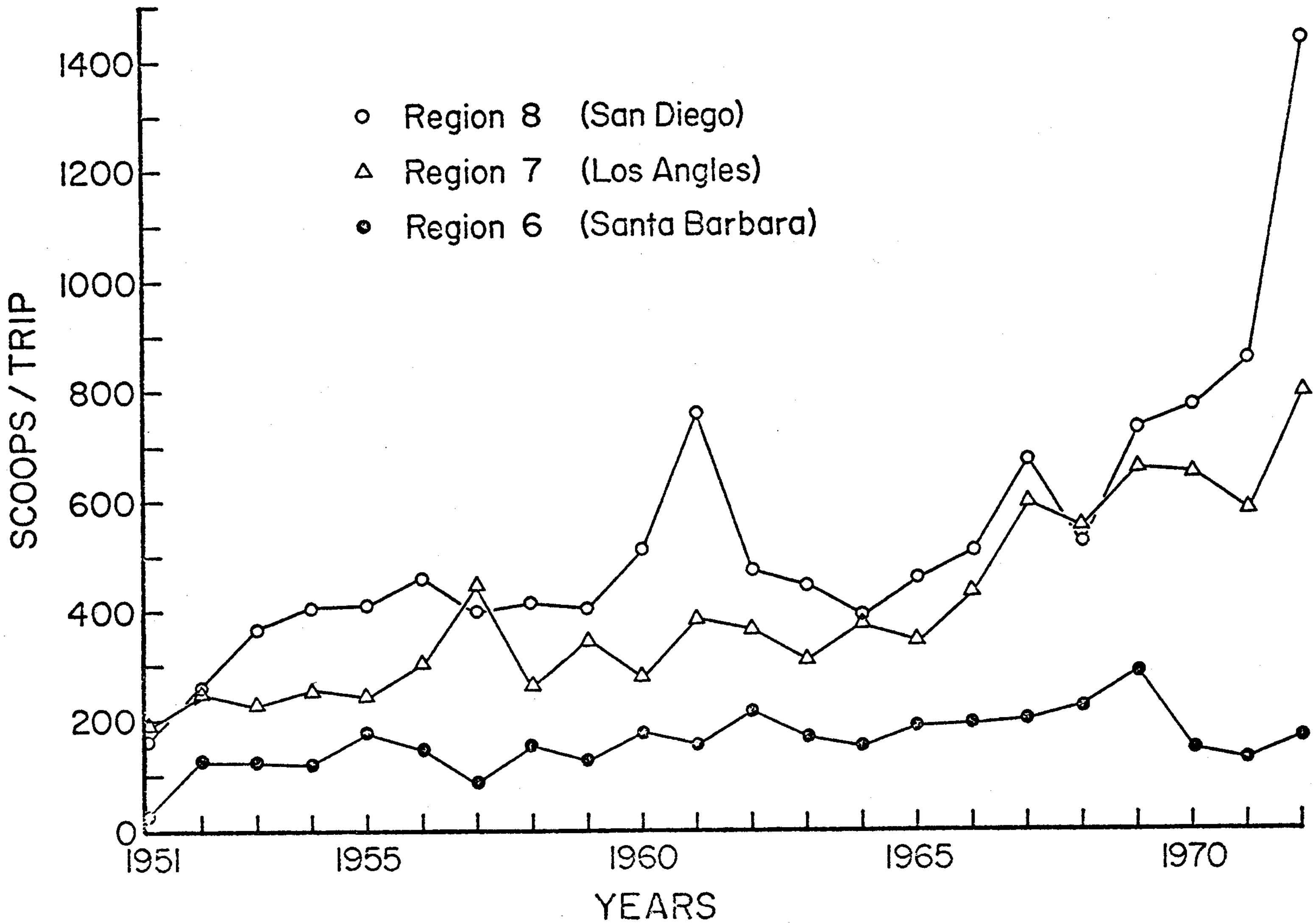

Figure 3.5-6. Anchovy live-bait catch per effort (annual scoops/trips).

Mean relative winter availability decreased 12 percent in both the Santa Barbara and San Diego regions but in the Los Angeles region in which reduction fishing is the heaviest, the mean ratio showed a 8.6% increase in relative winter availability. These analyses, though rather gross examinations of the data, did not detect any apparent relationship between the reduction fishery and availability of bait.

Using lampara nets, the bait fishery is not able to move offshore to avoid problems which seem to occur only inshore at times. The use of purse seine gear to take live bait has been largely unsuccessful due to injuries and mass "die-offs" when a net "roll-up" occurs. Recently, however, one bait fisherman has begun to experiment with a purse seine net which can be used for both bait and reduction fishery operations. The success of this venture may suggest a possible solution to some of the bait fishing problems.

3.6. Interaction between and among user groups

Two sources of interaction are potentially important. The proclaimed effect of commercial reduction fishing upon bait fishers and upon recreational fishers generally is the principal domestic conflict. Current regulations promulgated by California agencies are substantially influenced by the existence of, or perception of, the damaging effect a large commercial take would have on the coastal bait supplies. Also, there is a definite competition for use of the resource, defined broadly to include the fishing areas as well as the yield of the standing stock. That is, when recreational and commercial reduction fishing occurs in the same areas and at the same time, significant psychological conflicts are in evidence. Whether or not these conflicts rest upon scientifically substantiated species interactions, the commercial and recreational interests tend to take opposing views. To the commercial fishermen, there seems to be so many anchovy schools that the commercial harvest cannot possibly harm the abundant recreational species. To the recreational fishermen, the commercial harvest may appear to be an all-important factor in the abundance of bait and the abundance of highly-prized pelagic fish species in the heavily fished coastal area. Unfortunately, too little is known of the ecological interactions between the fish stocks to make a quantitative estimate of the influence the reduction fishery has on the recreational fisheries. Probably, the two points of view expressed by the recreational and commercial fishermen bracket the truth.

To lessen the conflicts between the two fishing groups, California regulations include closed zones and closed seasons for the reduction fishery. The closed zones tend to keep the commercial purse seine vessels out of near-shore areas which are heavily fished by recreationalists, and the closed seasons (May 15 to August 1 in the northern permit area, and May 15 to September 15 in the southern permit area) prohibit anchovy reduction fishing during the height of the recreational fishing season.

The second area of potential conflict is the international sharing of the central subpopulation of the northern anchovies between Mexico and the United States. Mexico's intent to develop her fisheries, the anchovy reduction fishery in Baja California in particular, could clearly lead to an interaction between the U.S. fishery and the Mexican fishery. Economically and socially, the two countries may easily have different definitions of what is optimal. Although the Mexican fishery draws upon the southern subpopulation of anchovies as well as the central subpopulation, Mexican harvests from the central population will tend to reduce the available surplus stock for a U.S. harvest and vice versa. A joint fishery management agreement between the two countries must be established. Through bilateral negotiations, an acceptable basis for managing and sharing the allowable yield from the stock would reduce the likelihood of real conflict.

3.7. State Revenues Derived from the Fishery

The California Department of Fish and Game (CF&G) collects revenues from the anchovy fishery through two privilege taxes authorized by the California Fish and Game Code. All revenues collected are deposited with the State Treasury in the Fish and Game Preservation Fund, from which both the Department of Fish and Game and the Fish and Game Commission are funded. Revenues collected by CF&G from license sales, fines and penalties are also generally deposited in the Fish and Game Conservation Fund. The two privilege taxes applied to anchovy fishing are specified in Article 7, Sections 8045 and 8046 of the Code. The Section 8045 tax consists of one dollar per ton of anchovies when anchovies sell for fifty dollars or less per ton, and two dollars per ton when anchovies sell for more than fifty dollars per ton. The revenues collected under this tax support the general operations of the Department and the Commission.

The other privilege tax imposed by Section 8046 requires payment of one dollar per ton of the following species: sardines, Pacific mackerel, jack mackerel, squid, herring, and anchovies. Revenues from this tax are to be kept in a separate account for use by the Marine Research Committee, a departmental committee consisting of nine members appointed by the Governor. The Marine Research Committee uses the funds from this tax to fund research "in the development of commercial fisheries of the Pacific Ocean and of marine products susceptible to being made available to the people of California" (Section 729 of the Fish and Game Code).

Both of the taxes are paid by the licensed packers or processors of anchovies. The total revenue collected by the State of California specifically due to the anchovy fishery is indicated in Table 3.7-1.

Table 3.7-1. Revenues derived from the anchovy fishery by the State of California, 1950-1976*

1950	$ 4,878	1959	$ 7,174	1968	$ 31,076
1951	6,954	1960	5,058	1969	135,278
1952	55,782	1961	7,712	1970	192,486
1953	85,836	1962	2,764	1971	89,706
1954	42,410	1963	4,570	1972	138,202
1955	44,692	1964	4,576	1973	265,272
1956	56,920	1965	5,732	1974	165,434
1957	40,548	1966	62,280	1975	317,022
1958	11,602	1967	69,610	1976	223,610**

* Fifty percent of this revenue is specifically for the use of the Marine Research Committee.

** Estimated from preliminary figures.

4.0. Biological Descriptions

4.1. Life History

4.1.1. Distribution

The population of northern anchovy Engraulis mordax is distributed from the Queen Charlotte Islands, British Columbia to Magdalena Bay, Baja California as discussed in section 3.1. The central subpopulation, the management unit of this plan, ranges from approximately San Francisco, California, 38°N to Pt. Baja, Baja California 30°N. The eggs and larvae are common out to 200 miles offshore and have been taken out as far as 300 miles in some years (Ahlstrom 1967, p. 121). Based on the relative abundance of anchovy larvae, the greatest density of anchovies is in the inshore regions (Ahlstom 1967, p. 121 and Smith 1972, p. 869).

The distribution and movement patterns of the northern anchovy in northern Baja California and southern California documented by Mais (1974, p. 29-43) are given as summarized by Knaggs (MS, p. 5-8). These seasonal patterns though are not well defined. The information is based on CF&G acoustic transect-midwater trawl surveys (frequently referred to as the sea surveys) for the period June 1966 to February 1973. "Anchovies in this area are widely distributed from shore to 157 km seaward. The greatest concentrations were generally within 37 km of shore over deep water basins.

"The more distant deep water basins lying 37 to 111 km offshore collectively contained the largest portion of the anchovy population in this region with small but very numerous schools distributed over large areas.

"Relatively small amounts of fish were found in the shallow banks and inshore waters. School groups or concentrations rarely exceed or equaled those of deeper water. However, these areas may be more important than results indicated since acoustic equipment, particularly sonar, is less efficient in detecting schools in shallow water. In addition, a common scattered schooling behavior in shallow water often made school enumeration difficult or impossible.

"Anchovy distribution within the Southern California Bight varied considerably both seasonally and annually. During the fall months, a large portion of the population was located inshore and in the more northern part of the Bight. Schools were generally larger in size but fewer in number than in any other season.

"Commencing in late winter, an offshore and southeasterly movement occurred coinciding with the onset of major spawning activity. At this time the population was widely spread over large areas offshore and south of San Pedro. Schools became extremely numerous and small reaching peak numbers usually in April or May. A return northward also occurred at this time with part of the population forming large daytime surface schools during some years. Time of formation of these schools varied from the middle of March to late June.

"Seasonal distribution in northern Baja California was less varied and different than in southern California. During a large portion of the year, anchovies were found in concentrations in deep water close to shore similar to the southern California fall distribution. In contrast to southern California, however, very few schools were detected during spring months, and few or nay fish were found more than 27.8 km offshore except near the offshore border area between the two localities.

"By far the most prevalent and common schooling behavior observed in the Southern California Bight was the formation of small very low density near surface schools during daylight hours. After dark, anchovy schools invariably dispersed into a thin surface scattering layer and remained so until the following dawn.

"Small low density schools near the surface were always found over bottom depths of more than 183 m and were widely distributed over thousands of square miles of sea surface area. Although they were found over deep water everywhere, they were the only type schools distributed in the more offshore areas. Schools of this type comprised an estimated 90% of all detected by sea surveys. They were dominant type during all seasons but were most numerous and prevalent during the late winter and spring. At this time, schools are very small (probably 0.5 to 6.0 tons) and wary. All the actively spawning anchovies collected during the sea survey were from this type of school.

"The rapidity of vertical migration and the large differential in temperatures encountered indicate a eurythermal tolerance for anchovies."

Baxter (1967, p. 110) reported that northern anchovies have been taken in waters of temperatures 8.5°C to 25.0°C. The temperature range for the central subpopulation is probably not as wide. Anchovy eggs have been sampled in temperatures ranging from 9.9°C to 23.3°C (Ahlstrom 1956, p. 38) but most eggs occur in temperatures between 13.0°C and 17.5°C In a study of the relationship of surface temperature to sexual development, Mais (1974, p. 48) found anchovies from the central subpopulation over a temperature range of 12°C to 21.5°C. The data indicated that a pronounced peak of spawning activity occurs in a range of 13.5°C to 14.0°C with minor peaks at 15.5°C to 16.0°C and 17.0°C to 17.5°C. In a recent study Brewer (1976, p. 441) presented a summary figure of the thermal limits for the distribution and survival of larval and adult anchovies, this is reproduced as Fig.4.1-1.

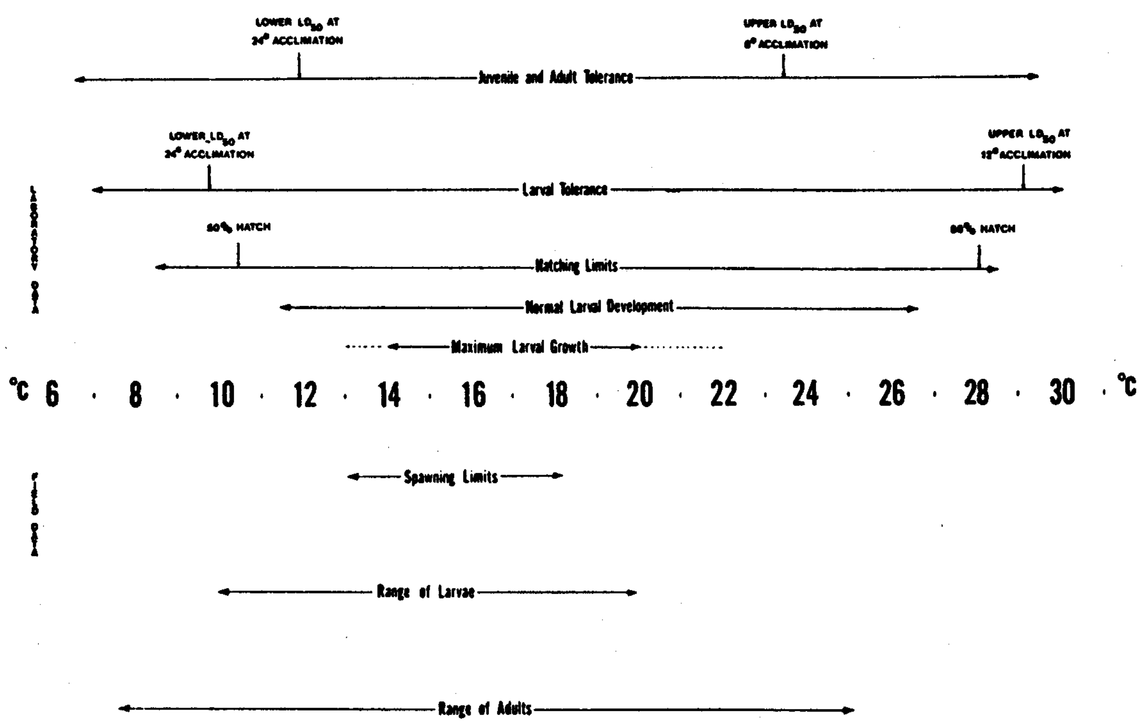

Figure 4.1-1. Field and laboratory deduced thermal limits for the distribution and survival of northern anchovy (reproduced from Brewer 1976, p. 441).

Tagging conducted in the late 1960's demonstrated anchovies move alongshore between central California area (San Francisco Bay to Morro Bay), and southern California in both a northerly and southerly direction (Haugen, Messersmith and Wickwire 1969, p. 81 and 82). There is some evidence from Haugen et al. (1969, p. 82) that anchovies in southern California move from offshore areas to inshore and vice versa. Anchovies tagged off Catalina and San Clemente Islands were later recovered in the Los Angeles-Long Beach Harbor. Tagged fish released in the Harbor area were caught in southern California fishing grounds and off Baja California. Knaggs (MS, p. 8) reported on one tagged anchovy that was released off San Diego and recovered at Monterey 129 days later. The fish traveled at least 370 miles at a rate of nearly 3 miles per day. Unfortunately the overall tag recovery rate was low.

Lasker (pers. comm., April 1977) measured the swimming speed of a small school of 90-100 mm SL anchovies in the laboratory at 3 body lengths per second. If a school of 130 mm SL anchovies maintained and average speed of 3 body lengths per second, they could travel a distance of approximately 34 kilometers in 24 hours. This is about 18 nautical miles or 21.0 statute miles. It is unlikely that a school travels in a straight line for a distance of 34 kilometers.

4.1.2. Age and Growth

The age of northern anchovies has been determined from annual rings on scales and otoliths. Clark and Phillips (1952) used scales for age determination. Miller (1955) verified that annuli on scales indicate the age of the anchovy. Collins and Spratt (1969) verified the use of otoliths for aging anchovies and concluded that the age composition obtained from otoliths did not significantly differ from that for scales. Because 40% of the anchovies sampled from the fishery did not have readable scales, California Fish and Game now uses otoliths for aging. Miller (1955, p. 24) found that scale annuli formed during early winter and spring months. Collins and Spratt (1969, p. 43) defined a completed annual ring for otoliths as the interface between an inner hyaline zone and an outer opaque zone. They indicated the peak time of ring formation in otoliths is late spring and that nearly all new rings were complete by June 1st.

In general, the anchovy is short lived; the average age of adults in an unexploited population is approximately 2.28 years (see Appendix IV.A).Some anchovy become sexually mature after 12 months of age (Clark and Phillips 1952, p. 205). According to recent work by CF&G, nearly 100% of the anchovies are sexually mature after 24 months of age, although Clark and Phillips (1952, p. 205) concluded only a small percentage are mature at the end of 2 years of life (E. Knaggs, CF&G, pers. comm., April 1977).

Recruitment of anchovies into the live-bait and reduction fisheries begins within the first year (Baxter 1967, p. 116 and Sunada 1976, p. 221). Anchovies are fully recruited to both fisheries during their second year of life (Sunada 1976, p. 221). Anchovies over 5 years of age are rarely caught in the commercial fisheries although anchovies 7 years old have been taken (Baxter 1967, p. 112 and Sunada 1976, p. 221).

Clark and Phillips (1952) and Spratt (1975) have presented growth curves for anchovies from commercial fishery samples. Size at the end of the year from these two papers are listed in Table 4.1-1. The samples of Clark and Phillips were from the fishery in central California while Spratt collected samples from southern California. At 12 months, anchovies are approximately 92 mm standard length (SL). In general, the mean length of anchovies at age are larger in central California than southern California (Collins 1969, 1971; Spratt 1972, 1973a, 1973b; Sunada 1975, 1976; and Mais 1974). Sakagawa and Kimura (1976, p. 278) estimated average lengths for anchovies reared in the laboratory were 102 mm SL for 12 month olds and 119 mm SL for 24 month olds. Recent work on daily growth rings shows some anchovies to be 75 to 90 mm SL at age 6 months (R. Methot, SIO, pers. comm., March 1977). Spratt (1975, p. 123) fitted the von Bertalanffy growth curve to back-calculated lengths for age groups 1 through 6 using otoliths. The equation is

$$l_t = L\infty \,(1-\exp\,(-K(t-t_o))$$

with parameter estimates $L\infty$ = 165.5 mm SL, K=0.2987 and t_o = -1.714. Total length (TL) of the anchovy in millimeters can be estimated by multiplying standard length in millimeters by 1.17111 (Clark and Phillips 1952, p.197). A 5-inch TL anchovy is approximately 110 mm SL.

The length-weight relationship has been found to vary significantly within seasons and between seasons (Knaggs, MS, p. 3).

Table 4.1-1. Average length at each age of the anchovy in the California Fishery (Clark and Phillips 1952, p. 204 and Spratt 1975, p. 124).

Age at end of year	Total Length Clark & Phillips (1952)		Total Length Spratt (1975)	
	mm	inches	mm	inches
1	108	4.2	108	4.2
2	140	5.5	131	5.2
3	163	6.4	145	5.7
4	178	7.0	158	6.2
5	189	7.4	170	6.7
6	196	7.7	182	7.1
7	200	7.9		

Collins (1969, p. 68) gave the following allometric relationship for southern California anchovies from the 1966-67 fishery:

$$\text{Female} \quad W = 1.0933 \times 10^{-5}\, L^{2.98408}$$

$$\text{Male} \quad W = 8.056 \times 10^{-6}\, L^{3.04859}$$

where weight, W, is in grams and length, L, is in mm SL. For these estimates the isometric relationship

$$W = 1.015 \times 10^{-5}\, L^{3}$$

appears to be approximately equivalent for the two sexes (see Table 4.1-2.).

Table 4.1-2. Estimated weight for various lengths from the allometric and isometric length-weight equations.

Length (mm)	Estimated weight (g)			
	Allometric			Isometric
	Male	Female	$\frac{M+F}{2}$	M + F
100	10.08	10.16	10.12	10.15
120	17.57	17.51	17.54	17.54
140	28.11	27.73	27.92	27.85
160	42.23	41.31	41.77	41.57

The oil content of the anchovy adult is cyclic over the season. It has a low in the winter and spring spawning season and increases in the summer to a peak around September (Lasker and Smith 1977, in press, p. 17). This cycle is given in Figure 4.1-2. During the low period, the oil in the flesh is replaced by moisture.

Menhaden fish oil has a specific gravity of approximately 0.93 at 15°C[1]. Assuming the same value for anchovy oil, then one gallon weighs about 7.75 pounds. The oil content of anchovies was reported by Messersmith (1969, p. 29) to fluctuate between 15 and 45 gallons per ton of anchovy (5.8 to 17.4% body weight) in Monterey and between 5 and 30 gallons per ton (1.9 to 11.6% body weight) in southern California. The low values occurred during the spawning season. Oil yields from laboratory studies are about 50-60% greater than those from reduction plants.

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[1] From Handbook of Chemistry and Physics, table of constants of oils, fats and waxes. Chem. Rubber Publ. Co.

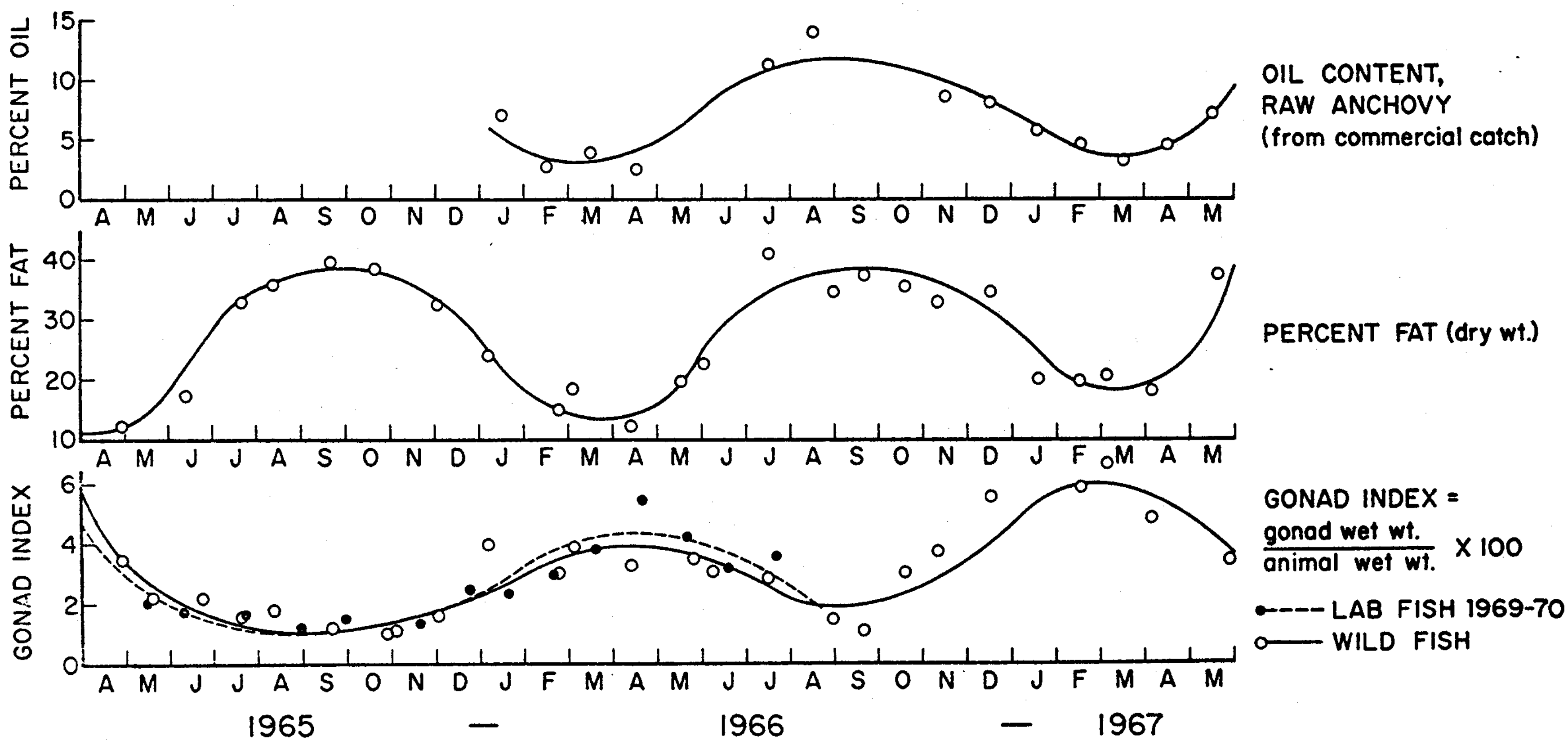

Figure 4.1-2. Annual northern anchovy fat and gonad cycles for 1965-67. (Lasker and Smith 1977, in press, Figure 5.)

The food of anchovies has been examined by Loukashkin (1970). He estimated the percentage of food items by number from stomach samples as crustaceans, 50.78%; other zooplankters, 35.76%; phytoplankton, 10.99% and foreign matter, 2.4%. Loukashkin (1970, p. 431), Baxter (1967, p. 112) and John Hunter (NMFS pers. comm., April 1977) have found anchovy eggs and larvae in the stomachs of adult anchovies but there is no measure of the magnitude. Consumption of eggs and larvae by the adults could act as a density dependent mechanism. Loukashkin (1970, p. 450) concluded that the northern anchovy is an omnivorous species feeding predominantly on zooplankters and to a lesser extent on phytoplankton. The most important food items of the adults are copepods and euphausiids. In relation to feeding habits, the anchovy is diurnal, feeding mostly during the day. The northern anchovy is primarily a filter feeder, but may also be a particulate or selective feeder, depending on the size of the available food. Experiments have shown that prey organisms less than 1 mm are consumed by filter feeding and organisms a few millimeters in length are taken by particulate biting (Anonymous 1967, p. 19).

4.1.3. Mortality

MacCall (1974) estimated the instantaneous rate of total mortality, Z, for anchovies in southern California from a catch curve analysis of the age composition samples taken from the CF&G sea survey trawling between October 1966 and April 1971 and the anchovy reduction fishery catch at San Pedro from the 1965-1966 to the 1970-1971 seasons. He assumed that natural mortality was constant over the adult life-stanza and that age 2 fish and older were fully recruited. Estimates of Z for the sea survey data ranged from 0.75 to 1.30 with a mean value of 1.09. By comparison estimates for the 5 years of fishery data ranged from 0.95 to 1.56 with a mean of 1.16. These latter estimates are less likely to be representative of the entire stock, since the fishery occurs in a restricted area of central stock. Because year class strength fluctuated over the years in question MacCall selected the average value of 1.09 as the best estimate of Z.

MacCall, Stauffer and Troadec (1976, p. 6) estimated the instantaneous rate of fishing mortality from the ratio $F = C/N$. They estimated F ranged from 0.02 to 0.04 for the recent years of the reduction fishery. This gives a remainder of approximately 1.06 for instantaneous rate of natural mortality, M. This implies that, under conditions of no fishing, only 33% of the anchovy in numbers survive to the next year.

The survival of anchovies in units of weights is greater since invididuals are growing, i.e., survival is e^{-F-M+G}. In Appendix IV.A., the value of M-G is found to be approximately 0.8. This implies that 45% of the adult anchovy biomass survives to the next year.

4.1.4. Reproduction

The size and age at first maturity was first examined by Clark and Phillips (1952, p. 204). They concluded that a few female anchovies first reached sexual maturity between 90 to 100 mm SL at the end of their first year of life. About 30% were maturing between 100 to 120 mm SL or 1 and 2 years of age. This increased to 50% for 120 to 139 mm SL fish between 2 and 3 years of age. More than 90% were maturing above 139 mm SL at the end of 3 years. Based on a current ongoing study, Knaggs (CF&G, pers. comm., April 1977) has concluded that some, but unknown percentage of 12 month old anchovies, are sexually mature and that 100% of anchovies older than 24 months are sexually mature. These preliminary data also suggest that larger fish of an age group mature earlier than smaller fish in the same group.

MacGregor (1968) examined the fecundity of a small sample of maturing female anchovies. He assumed that the number of eggs per spawning was equal to the number of eggs in the most advanced modal group in the ovaries. He found that the number of eggs was proportional to the weight of the fish for the length range of 97 to 138 mm SL. The mean of his sample was 574 eggs/gram with a 95% confidence interval of ±10% (MacGregor 1968, p. 285). A recent sample of 133 anchovies taken by CF&G had a mean of 557 eggs/gram (Knaggs, MS, p. 2); this is within MacGregor's confidence limit.

Spawning has been noted in every month of the year, particularly in the southern part of the anchovy's geographical distribution (Baxter 1967, p. 111). Based on the relative occurrence of anchovy larvae for each month, the peak spawning period is during the late winter and spring (Ahlstrom 1967, p. 122) (see Figure 4.1-3.). The frequency of later stages of gonad maturity is greater for larger anchovies (Clark and Phillips, 1952, p. 205). Knaggs (CF&G, pers. comm., April 1977) also finds that larger anchovies sampled by the CF&G sea surveys and from the reduction fishery have a higher frequency of later maturity stages for a longer period of time. This suggests that the number of spawnings per female during a season may increase with the size or age of the anchovy.

The sex ratios for anchovy samples from the San Pedro reduction fishery and CF&G sea survey trawl hauls indicate that adult anchovies are often segregated by sex. Klingbeil (in press, p. 3) found that the overall female to male ratio for samples from 1966 to 1975 sea surveys was 1.09:1, only slightly greater than the expected 1:1 ratio. On the other hand there were an inordinate number of samples with a large proportion of either males or females, particularly during February through June.

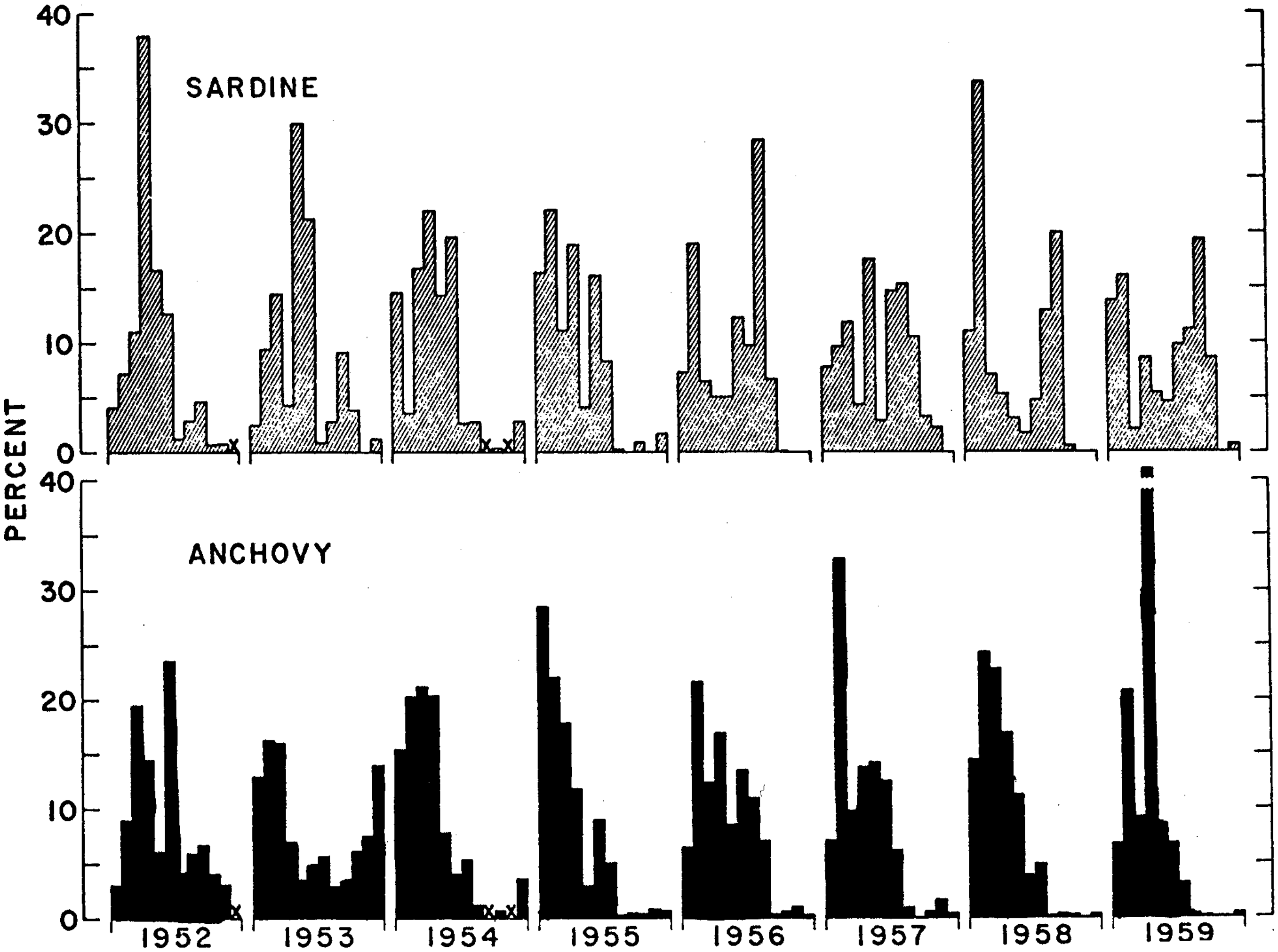

Figure 4.1-3. Percentage of the yearly total of sardine larvae (upper panel) and anchovy larvae (lower panel) taken in each monthly cruise, 1952-59. Spaces for each year on the abscissa depict a total of 12 months. "X" indicates no cruise was made (reproduced from Ahlstrom 1967, p. 122).

Samples from the reduction fishery are dominated by females throughout September through May season (Figure 4.1-4). The sex ratios only slightly favored males in just a few months. The sex ratios for the commercial fishery averaged 1.73:1 by weight for the past 10 fishing seasons (excluding 1967-68). The ratios ranged from 1.27:1 in the 1969-70 season to 2.18:1 in the 1973-74 season. The sex ratios by number and by weight as reported in the annual CF&G reports on the age and length composition of the anchovies in the reduction fishery are given in Table 4.1-3. (Sunada, 1975; Spratt, 1972, 1973a,b; Collins and Spratt 1969; Collins 1969, 1971).

Klingbiel (in press, p. 3) did not detect any consistent seasonal or cyclic trends in the sex ratios for either set of data. From a summary of the sea survey data by the monthly periods "February," "April," "May-June," "October," and "November," he found that the area generally southeast of San Clemente Island showed a consistent dominance of males, an area seldom fished by the commercial fleet (Fig. 4.1-5). The area to the north and west of Catalina Island was predominantly females. The samples from the Channel Islands-Port Hueneme area were consistently dominated by females for all monthly periods except October. He also noted that males generally dominated samples taken in the vicinity of Santa Monica Bay during the spring. His data also show that samples from San Pedro Channel area were dominated by females for "November" through "April" periods overlapping the commercial fishing season. This coincides with the female dominated sex ratios for the commercial fishery. The "May-June" and "October" periods in this area, on the other hand, were dominated by male anchovies. On the contrary, samples from the fishery have consistently favored females in the months of October and May. Consequently, we cannot conclude that a purse seine fishery operating during the summer months would take mostly male fish.

Table 4.1-3. The female to male sex ratios by number and weight for the San Pedro reduction fishery for seasons 1966-67 to 1975-76 (Sunada 1975; Spratt 1972 and 1973; Collins and Spratt 1969; Collins 1968 and 1971).

Season	Sex ratio by number	Sex ratio by weight
1966-67	1.58:1	1.77:1
1967-68		
1968-69	1.45:1	1.54:1
1969-70	1.14:1	1.27:1
1970-71	1.60:1	1.75:1
1971-72	1.52:1	1.60:1
1972-73	1.99:1	2.14:1
1973-74	2.02:1	2.18:1
1974-75	1.57:1	1.72:1
1975-76		1.61:1 1/
1976-77		
Mean		1.73

1/ Source: J. Sunada, CF&G, April 1977.

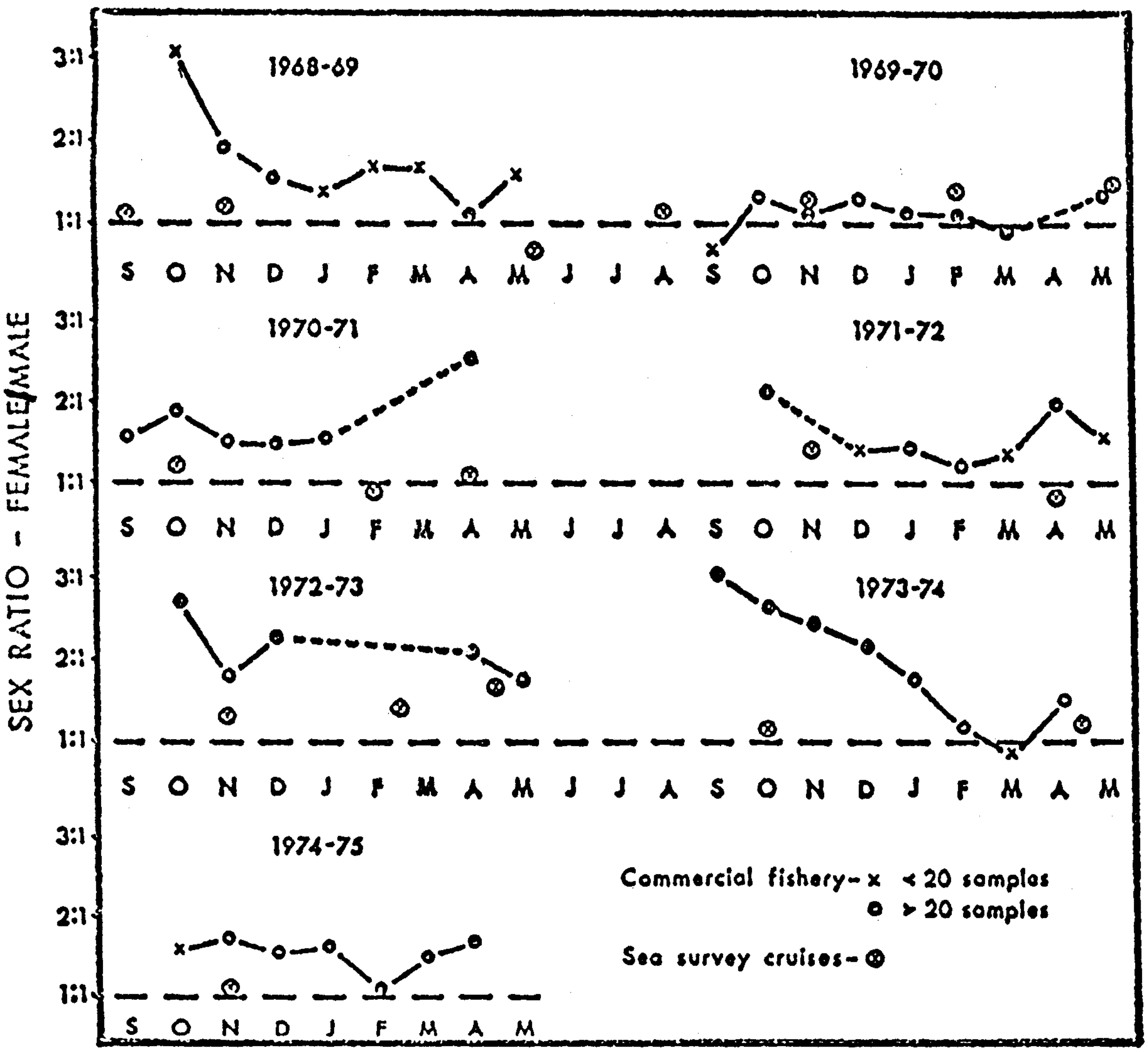

Figure 4.1-4. Sex ratios (F:M) of anchovies by month computed from samples taken from the commercial fishery (1968-69 through 1974-75 seasons) and from California Department of Fish and Game Sea Survey Cruises (from Klingbiel, in press).

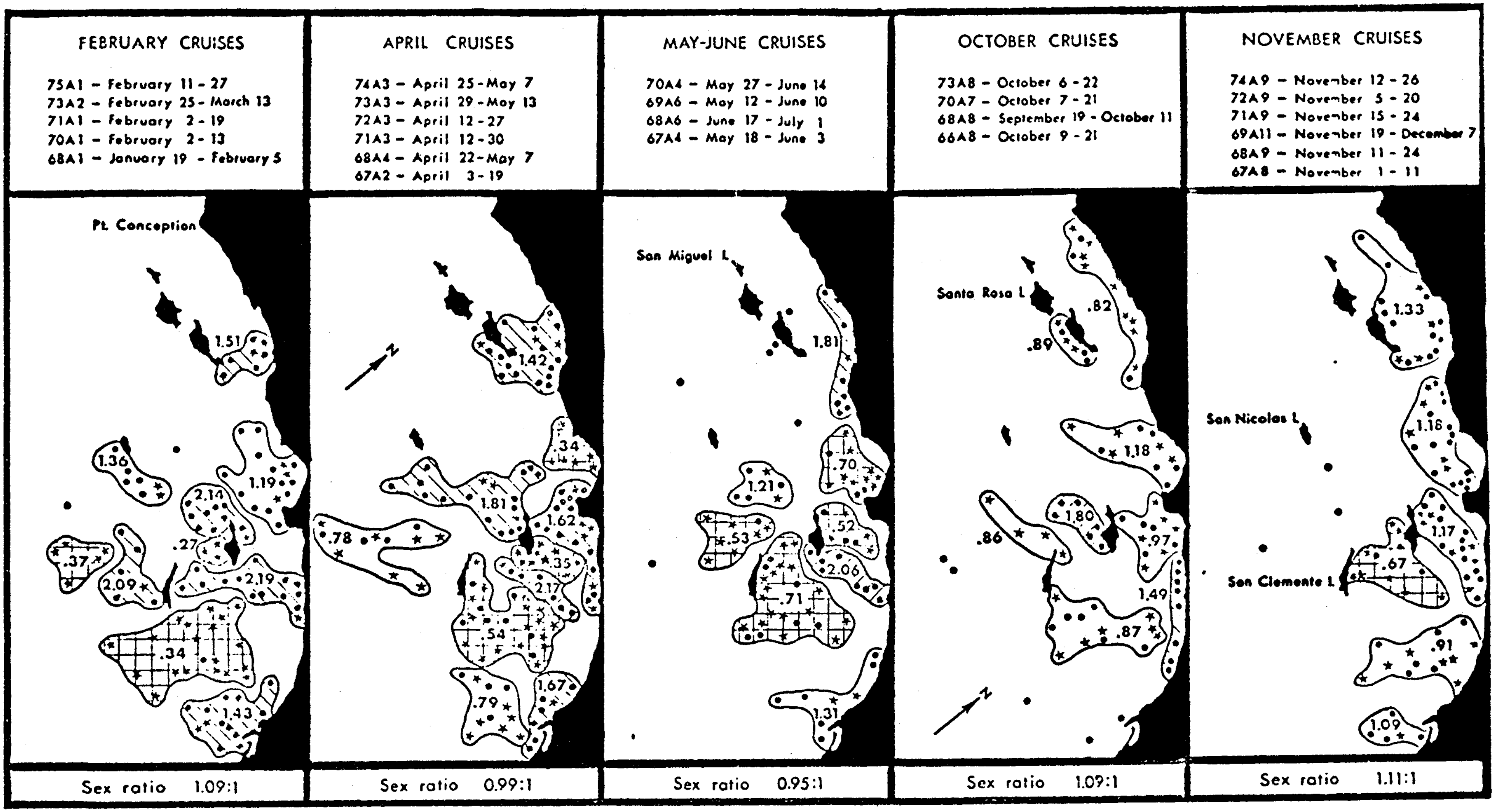

Figure 4.1-5. Sex ratios (F=M) of anchovies in time and space computed from samples taken by midwater trawl on CF&G sea surveys. Stars represent samples with a majority of males; dots represent samples with a majority of females. Hatched areas indicate strong male or female dominance in samples (reproduced from Klingbeil, in press).

develop a sampling procedure to assess the size of the incoming year class. It is hypothesized that the strength of an incoming year class is determined by the larval mortality rate (Hunter 1976, p. 1). The abundance of food particles of the proper size was found by Lasker (in press) to be critical to the survival of first-feeding anchovy larvae. He suggested that by monitoring the density and distribution of food particles during the spawning season that one could predict the success or failure of the year class in the making. As in most stock-recruitment relationships, one should expect a great deal of variability in recruitment to the anchovy fishery resulting from environmental factors. An analysis of the time series of the CalCOFI spawning biomass for the central subpopulation of northern anchovy suggests that recruitment is density dependent. The maximum estimated increase in biomass between two adjacent years has not been much greater than twofold (see Appendix II, Figure 2). Although there is a chance that a particularly strong year class might develop from a relatively low spawning biomass, it has not been a frequent event in the growth of the central subpopulation that can be planned on in the development of management strategies.

4.1.6. Predation

The anchovy is a prey species throughout all its life stanzas; egg and larva, juvenile and adult. The list of predators is long and includes almost every predator species of fish, birds and mammals in the California Current region (Table 4.1-4). Anchovy eggs and larvae, as part of the zooplankton complex, fall prey to the assortment of invertebrate and vertebrate planktivores including adult anchovies. Because of the rapid larval growth rates, the duration of this life stanza is about 2 to 4 months, but the mortality is high. As juveniles in the nearshore zone, anchovies are the most vulnerable to gamefish of recreational and commercial importance although these species must compete with a variety of other predators of less recreational value. Important recreational species in southern California are Pacific bonito (*Sarda chiliensis*), yellowtail (*Seriola dorsalis*), California barracuda (*Sphyraena argentea*) and in northern California, salmon (*Oncorhynchus* sp.) and striped bass (*Roccus saxatilis*). Less important species such as Pacific electric ray (*Torpedo californica*) and the abundant white croaker (*Genyonemus lineatus*) have been observed feeding on anchovy schools (A. Mearns, Southern California Coastal Water Resources Project, pers. comm. May 1977).

As adults offshore, anchovies are fed upon by numerous predators that include albacore, an important recreational and commercial fish, bluefin tuna, sharks, porpoise, seals and birds. Many of these predators are opportunistic feeders preying on whichever species is available. Unfortunately, very little is known about the actual quantities of anchovy consumed or the percentage of anchovies in the predator diets in relation to other forage species (Baxter 1967, p. 112). The annual amount of adult anchovies that succumb to predation is estimated as 73% of the initial spawning biomass when no fishing occurs. This percentage will decrease, as will the average initial biomass, as fishing pressure increases. The amount of biomass from the juvenile or prespawning stanza must also be large, but without estimates one can only speculate.

The impact of the anchovy fishery on marine birds is likely to be somewhat greater than that on other predators, since the purse seine fishery will directly compete for the surface schools on which marine birds feed. An extreme situation was experienced in Peru, where an intense purse seine fishery, combined with El Niño conditions, resulted in a severe decline in bird populations

Table 4.1-4 Known or Suspected Predators of the Northern Anchovy

Marine Mammals

Delphinus delphis bairdi	Common dolphin
Phocoenoides dalli	Dall porpoise
Lagenorhynchus obliquidens	Pacific striped dolphin
Callorhinus ursinus	Northern fur seal
Eumetopias jubatus	Steller sea lion
Zalophus californianus	California sea lion
Mirounga angustirostris	Northern elephant seal
Phoca vitulina	Harbor seal
Tursiops truncatus	Pacific bottlenose dolphin
Globicephala macrorhynca	Pilot whale

possibly Baleen whales
(except *Eschrichtius gibbosus*, the California gray whale, an endangered species, which does not eat during its migrations through California waters)

Marine Birds (* denotes endangered species)

Diomedea nigripes	Black-footed albatross
Fulmarus glacialis	Fulmar
Puffinus griseus	Sooty shearwater
" *puffinus*	Manx shearwater
Oceanodroma leucorhoa	Leach's petrel
" *homochroa*	Ashy petrel
Loomelania melania	Black petrel
Pelecanus occidentalis *	Brown pelican
Phalacrocorax auritus	Double-crested cormorant
" *penicillatus*	Brandt's cormorant
" *pelagicus*	Pelagic cormorant
Larus glaucescens	Glaucous-winged gull
" *occidentalis*	Western gull
" *heermanni*	Heerman's gull
" *delawarensis*	Ring-billed gull
" *californicus*	California gull
Rissa tridactyla	Black-legged kittiwake
Uria aalge	Common murre
Cepphus columba	Pigeon guillemot
Brachyramphus marmoratum	Marbled murrelet
Endomychura craveri	Craveri's murrelet
" *hypoleuca*	Xantu's murrelet
Synthliboramphus antiquum	Ancient murrelet
Ptychoramphus aleutica	Cassin's auklet
Cerorhinca monocerata	Rhinoceros auklet
Fratercula corniculata	Horned puffin
Lunda cirrhata	Tufted puffin
Haliaeetus leucocephalus	Bald eagle
Pandion haliaetus	Osprey

Marine Fishes

Alopias vulpinus	Common thresher shark
Isurus oxyrinchus	Bonito shark
Galeorhinus zyopterus	Soupfin shark
Prionace glauca	Blue shark
Torpedo californica	Pacific electric ray
Oncorhynchus kisutch	Silver salmon
" *tshawytscha*	King salmon
Sebastes spp.	Rockfishes (many species)
Roccus saxatilis	Striped bass
Paralabrax nebulifer	Barred sand bass
" *clathratus*	Kelp bass
Caulolatilus princeps	Ocean whitefish
Trachurus symmetricus	Jack mackerel
Seriola dorsalis	Yellowtail
Atractoscion (Cynoscion) nobilis	White seabass
Seriphus politus	Queenfish
Menticirrhus undalatus	California corbina
Genyonemus lineatus	White croaker
Embiotocidae spp.	Surfperches (many species)
Sphyraena argentea	California barracuda
Scomber japonicus	Pacific mackerel
Sarda chiliensis	Pacific bonito
Thunnus alalunga	Albacore
" *thynnus*	Bluefin tuna
Xiphias gladius	Swordfish
Tetrapturus audax	Striped marlin
Paralichthys californicus	California halibut

Invertebrates

Loligo opalescens	Market squid
DECAPODA (oegopsida)	Oceanic squids

(Clark 1975, p. 285). Maintenance of an anchovy population larger than that producing MSY, combined with appropriate area closures, should minimize the impact of the anchovy fishery on bird populations.

Of particular importance is the possible impact of the anchovy fishery on the food supply of the California brown pelican (Pelecanus occidentalis californicus), an endangered species. The two remaining breeding and nesting colonies in the southern California area are at Anacapa Island and at North Coronado Island. Little is known of the pelican's actual food requirements or of its alternative sources of forage. The pelican appears to be an opportunistic feeder, concentrating on the most abundant prey available. In southern California, anchovy is the major component of the pelican's diet. Pelicans require about two pounds of fish per day per bird, and can fly to feeding sites as far as 30 miles from the nesting colony, although it is not known if such flights are physiologically efficient. Forage requirements appear to be most critical at the time of nesting, which extends from February to September (above information supplied by Dr. Daniel Anderson, UC-Davis, personal communication). The Endangered Species Act of 1973 requires that Federal agencies (e.g., NMFS and FWS) insure that their activities and programs do not jeopardize the continued existence of listed species or result in the destruction or modification of "critical habitat" (which has been interpreted to include biota). The "critical habitat" of the brown pelican has not yet been officially determined.

4.2. Stock Units (see Section 3.1)

4.3. Catch-effort data

California Department of Fish and Game has maintained a fish receipt system since 1916 whereby fish dealers and processors, at time of delivery, record purchases of landed fish. For each transaction, the dealer records the species, weight, exvessel price, fisherman's name, vessel number, gear type, capture area, and intended use (McAllister 1976). These data are routinely edited, punched on cards, and summarized for various uses. These data could be used to calculate catch per trip statistics, but this is not done routinely for the anchovy reduction fishery. Receipts include landings for anchovy reduction, canning, dead bait, and fresh and frozen market for human consumption. They do not include the catch of anchovies for live bait used by recreational fisheries.

Operators of boats supplying live bait keep a voluntary daily log for number of sets, species caught, area fished, and number of scoops of bait sold. These records are something less than 100% complete. Periodically these records are analyzed and reviewed by CF&G (Alpin 1942; Wood and Strachan 1970; and Maxwell 1974), but at most, they are an indication of local availability of generally the younger age groups. Vessel logs are required of all boat operators who land anchovies for reduction. The format for these logs has changed a number of times since their beginning in 1965, but they provide the necessary data for calculating catch per trip, catch per set, area of catch, catch per hour where time may be time away from port, or hours searching. Logs for unsuccessful trips are not reported. The quality of the logs as in most other fisheries varies depending on the vessel operator. These data have been processed and summarized for the 1965-66 and 1966-67 seasons (Messersmith 1969). Since then, routine updates of catch based on CPUE of the reduction fishery which operates in a limited area with respect to the range of the central stock is quite unlikely to be representative of the central stock as a whole. Furthermore, the vulnerability of anchovies in the San Pedro Channel to the commercial purse seiners undergoes large fluctuations over very short time periods. These changes are more likely a result of environmental and behavioral factors rather than changes in overall abundance. A third important complicating factor is the limited vessel hold capacity and reduction processing capacity.

A fishing trip for anchovy reduction is almost always less than 24 hours and usually no farther than 50 miles from port. Because of limited reduction capacity, processors often impose landing limits on the vessels which are generally less than the vessels carrying capacity. In many instances, it is possible for the vessel to catch its limit in 1 or 2 sets. Aerial fish spotters routinely scout for fishable concentrations of fish and in many cases direct the setting of the net. This minimizes vessel search effort and increases the success rate. As a result, the catch per trip or catch per hour may reflect vessel or reduction capacity more than abundance of the stock.

Recently, NMFS-SWFC and CF&G initiated a cooperative study to process, analyze and evaluate a sample of reduction logbook data as a source for CPUE information. This is being done through the CalCOFI-INP (Mexico's National Fisheries Institute) Subcommittee on Catch-Per-Unit-Effort.

4.4. Survey and Sampling Data

Four major on-going surveys and sampling programs exist for the purpose of monitoring the fishery resources off California with particular emphasis on northern anchovies. These are the CalCOFI egg and larva surveys, aerial marine resource monitoring survey, CF&G sea surveys and the fish landings sampling program.

The first of these, the egg and larva surveys, provides the 25-year time series from which the estimates of the anchovy spawning biomass used in this management plan are derived. The estimates and the estimation procedures from this survey are extensively reviewed in Appendix I. During the period 1951-1960, egg and larva surveys were conducted annually with monthly cruises over the major portion of the anchovy range. During 1961-1965, annual surveys were conducted with one cruise per quarter. Beginning in 1966, surveys were run every third year with 8-10 monthly cruises per year. The next triannual CalCOFI survey begins in December 1977 and extends into October 1978. The objective of the survey is to monitor the abundance and distribution of eggs and larvae of various fish species in the California Current area as an indirect measure of the biomass of a fish species that spawned the eggs and larvae.

The aerial marine resource monitoring survey is conducted by commercial fish spotter pilots scouting for pelagic fisheries within generally the Southern California Bight. They are contracted to NMFS to record observations on a flight log of pelagic species, giving location, number of schools, estimated tonnage of each school or groups of schools, and flight track for each survey flight. This program was initiated in 1962 and is currently ongoing. Results of this survey were first reported on by Squire (1972). The majority of fish spotting effort is directed toward the location and catching of northern anchovy; jack mackerel, Trachurus symmetricus; Pacific bonito, Sarda chiliensis; Pacific mackerel, Scomber japonicus; and bluefin tuna, Thunnus thynnus for the recent years in the survey area. Flight operations are conducted during daylight hours or on nights during the dark phase of the moon at altitudes of 500 to 1200 ft. above the sea surface (Squire 1972, p. 1007). This survey is essentially flights of opportunity rather than a systematic survey, consequently it suffers from many of the same problems of CPUE data. Effort in this case is number of CF&G block areas flown over during a flight. Fish school tonnages are coded to simplify tabulation. The 15-year time series is presently being coded so that the data can be extensively analyzed with the aid of a computer.

Mr. James Squire of NMFS-SWFC has updated this index for northern anchovy in the area of the commercial fishery (Figure 4.4-1). For the northern anchovy, the night index rather than the day index is the most appropriate. The index was relatively stable for 1962 through 1972 with an average of 3.57. In 1973, the index peaked and has since shown a downward trend. The average of the index since 1972 is 9.92. The average for the 15-year time series is 5.29. The value of the index for 1976 is 5.37. For the 15-year time series, the index is below 5.37 in 10 years and above 5.37 in 4 years.

The sea surveys conducted by CF&G have two components, daytime sonar surveys and nighttime midwater trawl surveys. Data from these surveys are routinely published in annual CalCOFI data reports. Mais (1974) documented the finding of these surveys from 1966 to 1973. Although CF&G routinely use horizontal scan sonar to estimate the abundance of anchovies in the Southern California Bight (Figure 4.4-2) there are a number of practical problems with the method that are currently research topics and that produce questionable estimates of biomass (Hewitt 1976, p. 152). This is particularly so when the ocean's thermocline is shallow. The midwater trawl surveys provide data on length and age composition, sex ratios and sexual maturity of the anchovy resource in the Southern California Bight. These data often suffer from small and infrequent samples although the area surveyed is considerably larger than the fishery. Sea surveys are generally conducted 3-5 times per year.

The catch sampling program conducted by CF&G is a well designed stratified two-stage random sample of the commercial reduction landings. The anchovy reduction landings at Terminal Island canneries are sampled using a stratified random sampling plan with subsampling without replacement. The boatload is the primary unit and is selected randomly with probability proportional to its expected size. A secondary unit of 250 grams is chosen randomly and without replacement. A stratum consists of approximately 5,000 tons and 20 samples are taken per stratum. There is no sampling at Oxnard. Sampling in central California is slightly modified since quantity of fish landed is less and since the time and order of arrival of boat loads is unknown before sampling (Collins 1971, p. 283). All fish in the samples are measured for length and weight, sexed, and state of maturity assessed. Otoliths are taken from each fish for age determination (Collins 1971, p. 284). The age composition, sex ratios, maturity data are reported in sections 4.1 and 4.7.

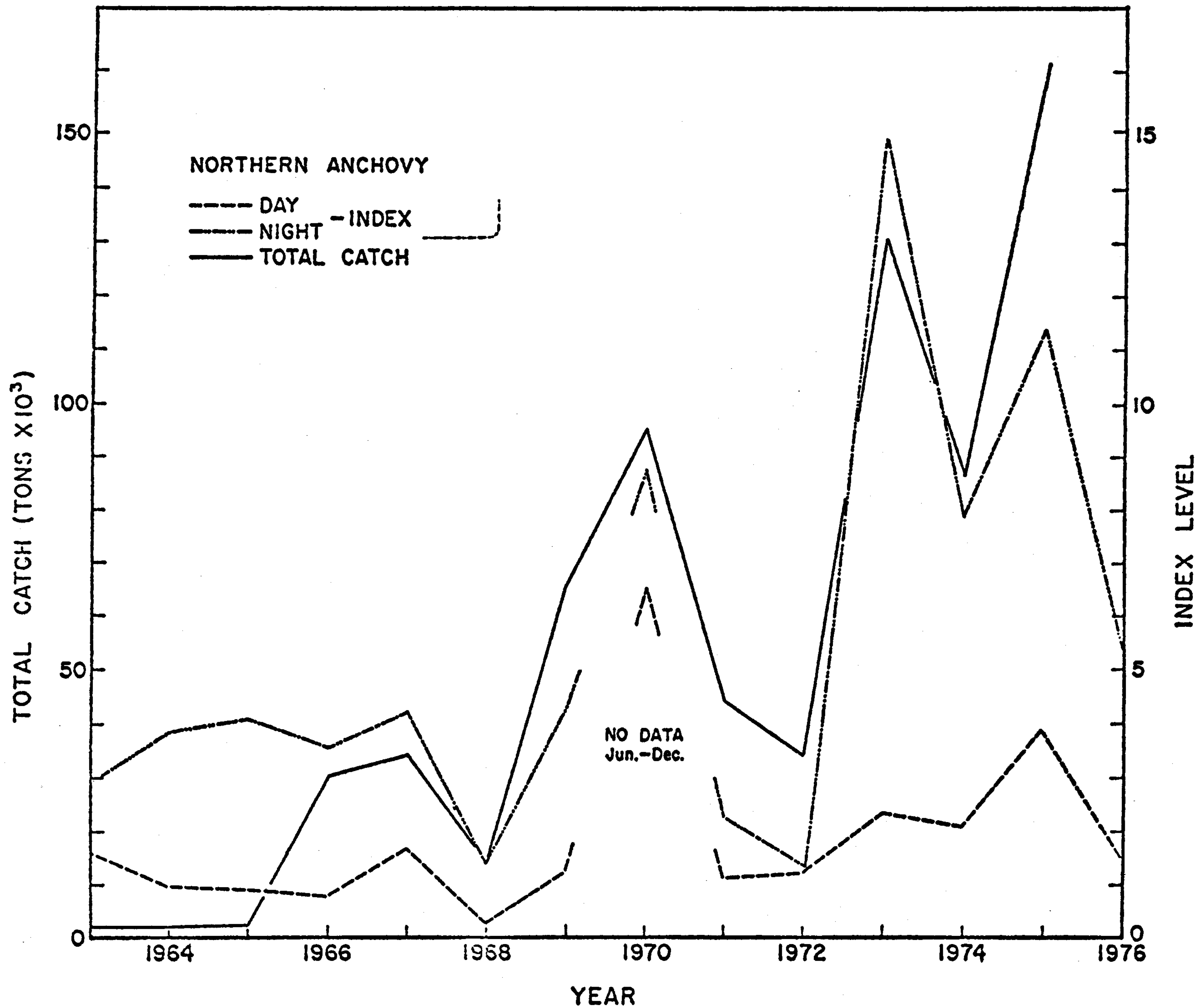

Figure 4.4-1. Aerial index of northern anchovy in region of the U.S. commercial fishery.

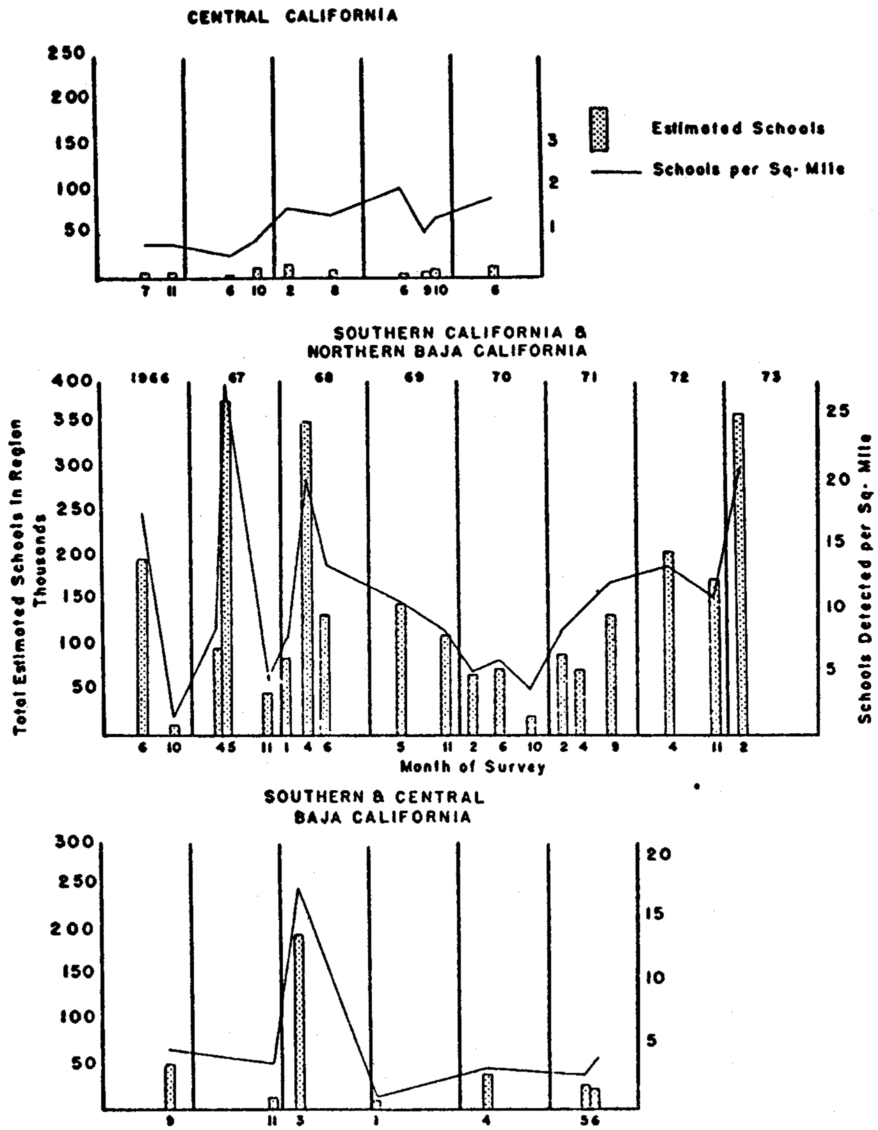

Figure 4.4-2. Anchovy acoustic survey results estimated from horizontal ranging sonar operation. Each bar represents an estimate of total anchovy schools inhabiting a particular region during a single survey. Solid line represents the number of schools detected per square mile of sea surface area. (Mais 1974, p. 22).

4.5. Habitat

The northern anchovy is an epipelagic species although it has been observed at depths of 300 m. Adults tend to remain relatively offshore. Juveniles are often found close inshore, in shallow waters, and in estuaries, as well as offshore.

Adult anchovies have been regularly observed in waters ranging from 12 to 20°C surface temperature in southern California. There is some evidence that anchovies tend to avoid high surface temperatures by remaining deeper in the water column, as demonstrated by the anomalous conditions in November 1976 (Mais 1976). Spawning usually occurs in temperatures between 12 and 15°C, which are typical during late winter.

There is little information regarding water quality requirements and preferences. Anchovies often congregate in areas of sewage outfalls, as in the case of White's Point off the Palos Verdes Peninsula. There have been periodic die-offs in Santa Cruz Harbor, and occasional cases of die-offs in Fish Harbor at Terminal Island when dissolved oxygen became too low. In the case of Santa Cruz Harbor, the low oxygen levels were caused by dinoflagellate blooms, and in Fish Harbor by excessive dumping of high BOD hold water and fish offal (the problem has been largely rectified). In both cases, die-offs occurred in harbors with very poor water circulation, but with attractive food supplies preliminary to the event.

The impact of the cannery waste has been studied in only the Los Angeles Harbor area. In this case, anchovy reduction processing is only one of the various fishery products that contribute to cannery effluent. Cannery wastes for many years were dumped into Inner Fish Harbor along with pumpings from boat holds and human wastes. In 1964, discharges were relocated and piped to two outfalls on the east side of Pier 301 (Soule and Oguri 1973, p.7). The Way Street Station receives wastes from various canneries and the other discharges effluent from only Starkist canneries. The discharge of cannery wastes are most critical during the fall of the year when seasonal die-off of biota from late summer and early fall plankton blooms and thermal turnover place a heavy natural oxygen demand on the receiving waters (Chamberlain 1975, p. 13). Soule and Oguri (1976, p. ii) report that "under present conditions, a small zone within approximately 200 feet of the outfalls exists where numbers of species are low. Adjacent to this zone is a zone of enrichment which extends through most of the outer harbor. Beyond that, conditions return to average coastal populations. The regulations of waste loadings and control of pollutants in the past 6-year period has brought the harbor ecosystem from a depauperate biota to a moderately rich one in the immediate outfalls zone, with a very rich biota in the adjacent outer harbor area."

Soule and Oguri (1973, p. 15-16) reported that "Nothing is known about the distance traveled by individual anchovies within the harbor, nor about the degree to which they move in and out of the harbor. Catches by the bait boats, presently being surveyed, indicate that there may be an area of inhibition in the immediate vicinity of the cannery outfalls . . . There are indications that the anchovies move away from the area when the oxygen is low and also when it is excessively high, during plankton blooms. Weather conditions may exert influence as well, for anchovies apparently disappeared from harbor catches prior to heavy winter storms and subsequent rainwater runoff. They also were not caught in the harbor near the end of the season when the Davidson Current brought warmer southerly waters into the area, but reappeared just after water temperatures dropped."

Recent studies (Lasker, 1975, 1976; Lasker and Smith, 1976) have shown that larval habitat is critical to larval survival and therefore governs subsequent recruitment strength. Spawning occurs from January to May throughout the area inhabited by the central stock, with heaviest concentrations occurring inshore. Favorable larval habitat consists of dense plankton blooms of edible and nutritious organisms. Edibility is governed by size, but nutrition is governed by species. Some organisms of the proper size, such as armored dinoflagellates, cannot be digested by the anchovy larvae. These plankton blooms characteristically form as thin layers often extending over large geographic areas.

Formation and destruction of these thin layers are the key events to larval survival. Upwelling must initially bring nutrients to the surface, allowing a plankton bloom to occur. Subsequent conditions must be stable, such that layers of planktonic forage attain sufficient concentrations for anchovy larvae to feed efficiently. Disturbance of these layers results in dispersal of the plankton, and concentrations may drop below levels necessary for survival. In the spring of 1974, Lasker (1975) observed the extensive destruction of plankton layers by a severe storm. Although this storm was a short-lived phenomenon, it may have been a contributory cause of the extremely poor 1974 year class of anchovies (see section 4.7). In the following year, Lasker (1976) observed destruction of the layers by a period of intense upwelling during the midst of spawning. Optimal larval habitat, therefore, depends on a delicate balance between too little and too much wind, which in turn affects the extent and timing of upwelling as well as direct agitation of the water column.

The extremely low anchovy biomasses observed by CalCOFI surveys in the early 1950's are coincidental with conditions which could have resulted in poor larval habitat. Moreover, Smith (1972) shows that the total anchovy stock was relatively large in 1940 and 1941, but was small when the CalCOFI program resumed in 1950 and 1951. A series of poor recruitments must have occurred between 1941 and 1950. Larval habitat for part of the period can be inferred from Bakun's (1973) upwelling index for the point 33°N, 119°W which is located in the Southern California Bight. Bakun's index is calculated from presumptive wind stresses as evidenced by barometric pressure gradients. Therefore, Bakun's index is not only indicative of probable upwelling, but even more so of probable atmospheric disturbances. The index extends from 1946 to the present, and the period 1947 to 1952 is anomalous in that the index was consistently lower than at any time before or since (Figure 4.5-1). The main contributor to these anomalies was lack of wind in the spring quarter. These data support a hypothesis that recruitment may have been poor due to insufficient upwelling resulting in insufficient food concentrations, although what concentrations there were probably remained undisturbed.

The consistency of the period 1946 to 1952 relative to the range of index values observed since then suggests the possibility of "favorable" and "unfavorable" regimes. We are presently in what appears to be a "favorable" regime, however, the possibility of entering an "unfavorable" regime always remains. The limited data available do not allow examination of mechanisms, or calculation of probabilities. This management plan assumes that present "favorable" regime will continue, while incorporating safety measures that will minimize the impact on the stock, should we enter an "unfavorable" period.

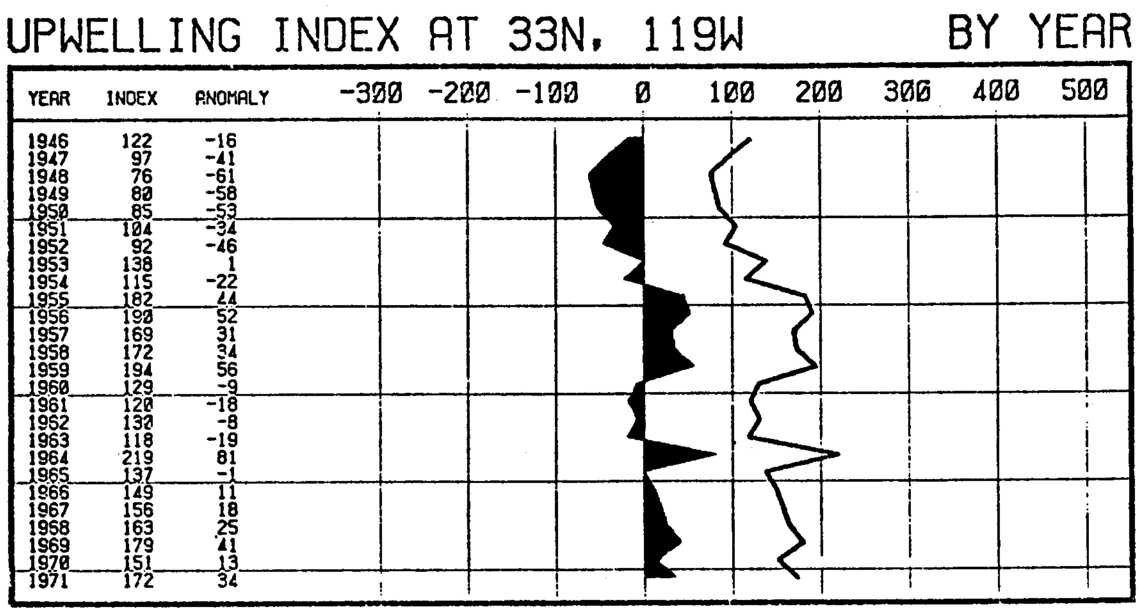

Figure 4.5-1. Annual upwelling index values and anomalies for the Southern California Bight (from Bakun, 1973).

4.7. Current Status of Stock

The stock is now being harvested at a rate of about 200,000 short tons per year between the California and Mexican fisheries. This is theoretically a large enough harvest to be able to observe an effect on the population size, but the large natural variability in biomass would mask any definitive changes over the short term.

In 1975, the central stock spawning biomass was estimated to be 3.6 million short tons. The next CalCOFI survey will be in 1978. The present population size can only be guessed at, using indications of recruitment strength from age composition information. The 1974 year class was extremely weak, and the 1975 year class was poor (Figure 4.7-1). The 1976 year class is making an early appearance and appears to be considerably stronger than the previous 2 year classes. The spawning biomass in the spring of 1977 was probably in the vicinity of 2 million tons, this being an "educated guess" based on apparent recruitment strengths. CF&G acoustic surveys of the Southern California Bight in the spring of 1977 gave estimates of about 1 million tons of anchovy biomass. This is consistent with the above guess since about 50% commonly occur in the Bight (see Section 3.1, Figure 3.1-3). As of the fall of 1977, the 1976 year class is making a strong appearance, and overall anchovy abundance seems to be increasing, and the stock has probably recovered to more "normal" levels of abundance. The 1978 CalCOFI survey should supply at least a preliminary estimate of abundance by mid-1978 sufficient to implement a sound management plan.

There is little danger of depleting the stock under existing California management. However, the existence of an independent and presently unregulated fishery in Mexico is cause for concern, and steps toward cooperative management must be initiated without delay.

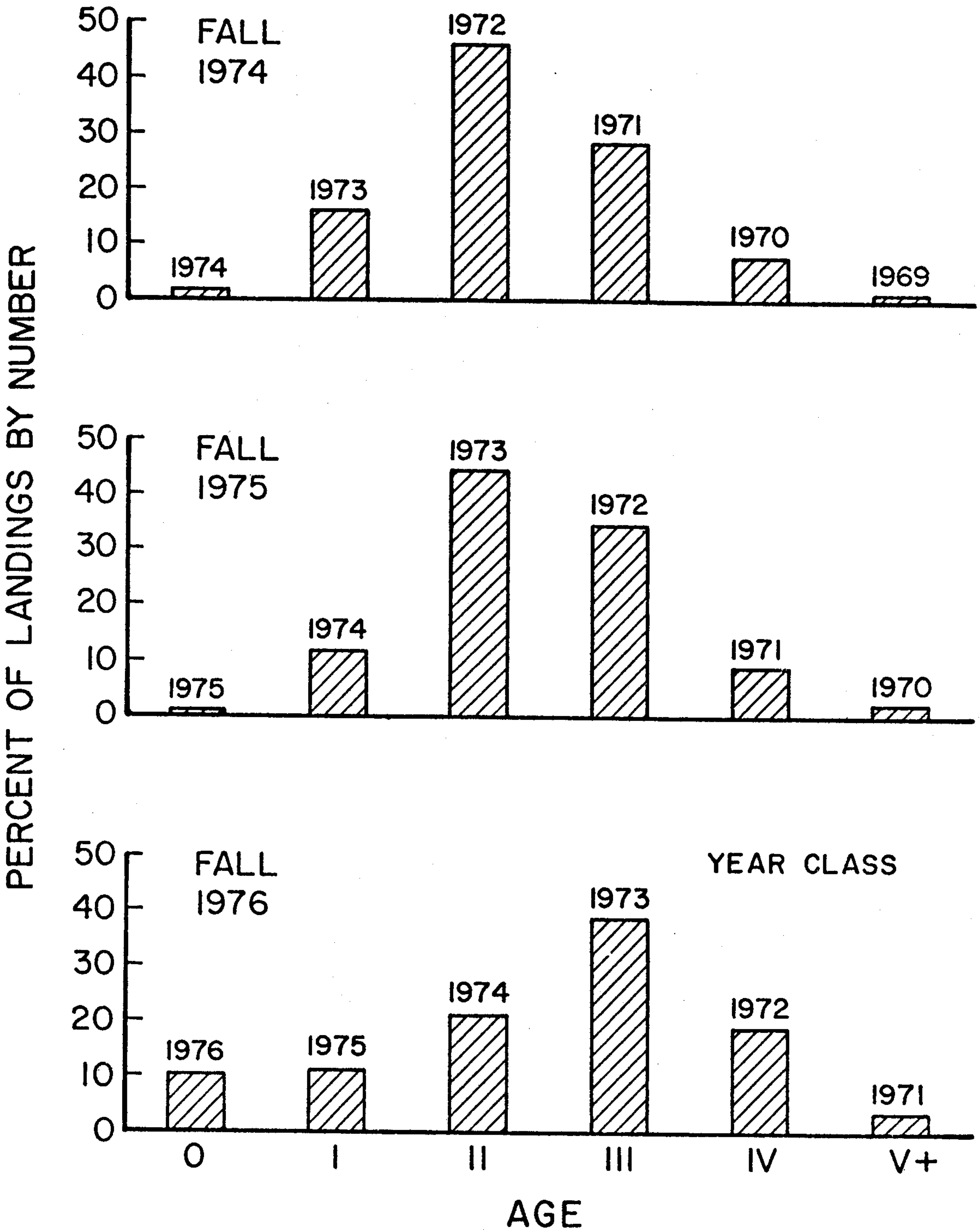

Figure 4.7-1. Recent age compositions from San Pedro fishery landings suggesting relative year class strengths.

4.7.1. Maximum Sustainable Yield

Sustainable yield can be approached from two viewpoints and can be evaluated using the population growth model described in Appendix II. First, we can ask, "If we seek to maintain the population at its most productive level, what is the largest harvest we could take such that the population size in the following year would remain unchanged, on the average?" If only post-spawning fish were harvested, this catch would be 560,000 tons, at a spawning biomass of 1.7 million tons. Since pre-spawning fish normally comprise a portion of the actual harvest, capture of pre-spawners (assumed to be 76% vulnerable for 0.2 years before spawning) results in this MSY dropping to 484,000 tons, at a spawning biomass of 1.8 million tons. Unfortunately, this approach is not useful for managing a fishery as variable as the one in question. The population size will almost never be near that giving maximum production in this sense. A more important problem is to determine the optimum harvest when we are not at 1.8 million tons of spawning biomass.

Therefore, a second approach is to ask, "What harvesting policy will give the largest yield while minimizing the variation in annual catches, and while minimizing the risk of extremely low levels of biomass?" This aspect of MSY cannot be answered with a single number. A policy giving the maximum average yield could conceivably produce as much as 520,000 tons, but the fishery would be required to maintain an extraordinarily large capacity while not being allowed to fish in two out of three years. The fishery would be prohibitively variable, and the average population size would be unacceptably low. At the other extreme, a constant quota of between 100,000 and 200,000 tons could be sustained for long periods, while maintaining quite high levels of biomass. There would still have to be a provision for curtailing the fishery if biomass fell below a critical level, such as 1 million tons.

In the anchovy fishery, the concepts of "maximum" and "sustainability" tend to be mutually exclusive due to large natural fluctuations. The determination of MSY requires a probablistic answer, and the variation in catch that constitutes "sustainable" must be given as an input to the analysis.

4.7.2. Equilibrium Yield

Figure 4.7-2. shows equilibrium yield under the first definition, where the resource is expected to remain unchanged in abundance, where the given yield is that harvest which would result in an unchanged population size on the average. Yields are compared for a) adult fish only, b) catch of some prespawners, and c) expected population growth in the absence of a fishery. Harvest levels are larger than growth levels since biomass is an annual measurement, and many fish can be harvested which would normally die of natural causes during the year and would not contribute to the population size at the time of measurement.

Since the population is highly variable, sustainability must be sacrificed somewhat in order to maintain the population at that size which produces desired equilibrium yield on the average. Therefore, less than that yield should be taken when the biomass is low, allowing the stock to recover. Conversely, we may wish to harvest some of the surplus when the biomass is larger than that producing the desired equilibrium yield. Such a harvest policy can be described by a line intersecting the yield curve at the desired equilibrium yield point, falling below the curve to the left of that intersection and rising above on the right. The mean yield will generally be approximately that indicated by the point of intersection, while the variability about that mean will increase as the slope becomes steeper. Protection against very low biomasses is obtained by maximizing the growth potential in general, but particularly at those low biomass levels.

For simplicity in describing these policies, the plan has used harvest formulas consisting of straight lines. Insurance against low biomasses has been sought by imposing a level of biomass at which the fishery ceases. Various options regarding these harvest policies are given in Section 8.3.6.

5.0. Catch and Capacity Descriptions

5.1. Fishing fleet capacity

The term "capacity" has several different meanings. The most common meaning in fisheries is that of hold capacity. Of the 102 vessels reporting some anchovy landings (not including bait catch) during the years 1973 through 1975, the hold capacities for anchovies are known for twenty-four vessels (CF&G, pers. comm.). Because all commercial fishing vessels in California must register with State authorities, the registered length of each anchovy vessel is known. To the extent that length of vessel and anchovy hold capacity are related, the hold capacity for the entire fleet can be estimated statistically. A moderately accurate linear relationship between registered length and hold capacity is represented by the following linear regression equation:

$$\text{Hold capacity in tons} = .2289 + 1.73\ (\text{registered length in feet}),$$

with a correlation coefficient of .773.

By estimating the hold capacity of each vessel with the regression equation, and summing up capacities for all currently active vessels landing anchovies during the 3-year period, 1973-75, a fleet capacity estimate of 7,688 short tons is calculated. This estimate includes the capacity of many vessels not particularly active in the anchovy reduction fishery. Some of the vessels included land only very minor quantities, and some have not participated in the last year. Industry sources indicate that the "core" of the southern California reduction fishery has about 4,500 short tons of hold capacity.

From the estimate of hold capacity it is possible to obtain a rough estimate for fishing fleet capacity. The fishing fleet will most likely not utilize completely the fleet hold capacity for all trips. Under the assumptions that on the average 9/10 of the hold capacity is filled, that fishing takes place five nights a week, and that one week of fishing is lost each month due to bright moonlight, then the present maximum fishing capacity is 486,000 short tons for a 32-week fishing season. However, it is unlikely that the fishing fleet will actually harvest this amount of anchovies. The effective constraint to the amount of fish harvested is not the hold capacity of the fleet, but the processing capacity. The fleet will not harvest a greater amount of fish than can be handled by the processors.

The abundance and availability of fish to the fleet will affect the extent to which the peak fishing capacity can be utilized. In the 1975-1976 season for instance, while the peak weekly anchovy reduction landing was 8,675 short tons, the average weekly landing during the season was only 4,406. If the availability of fish is responsible for the shortage of actual catch and if it continues to have this effect, then the catch of the fleet cannot be expected to exceed 247 thousand tons in the 32-week fishing season. The length of the fishing season will also influence the capacity of the fleet. If a year-around reduction fishery were allowed, the hold capacity would allow the fleet to harvest 789 thousand tons per year rather than 486 thousand tons. Considering the availability of fish, the annual yield might reasonably be expected to have a maximum value of 401 thousand tons.

Any estimate of fleet capacity at this time must be preliminary because the fleet has never actually fished unconstrained by reduction landings quotas, season closures, and limits reflecting processing capacity. Economic factors; such as exvessel price, operating costs, alternative earnings possibility, and capital costs; will determine whether or not the fleet owners and operators seek to fully utilize the fleet capacity. Thus the capacity estimates cannot be used as predictors of annual harvest.

5.2. Processing Capacity

The estimation of processing capacity is decidedly easier than the estimation of fishing capacity. Two approaches to the estimation of processing capacity are apparent--one stemming from the "nominal" production capacities of the reduction plants in place, and the other relying upon observed performance of the plants. The "nominal" capacity of a plant reflects the engineering and design characteristics of a plant, whereas the performance of a plant results from economically motivated decisions of the plant operator, business conditions, and the physical condition of the plants. The reduction plants involved in anchovy reduction at Terminal Island, California, are nominally capable of processing 149 short tons of anchovy per hour. The plants at Oxnard, Moss Landing and Salinas have a collective nominal capacity of about 36 short tons per hour. If all these plants were to run for, say, twelve hours per day for 365 days a year, the annual nominal capacity would be 810,300 short tons. Taking into consideration the 32 week fishing season under current California regulations and the loss of an average of 1 week out of 4 due to the reluctance of the fishing fleet to fish during periods of bright moonlight, the likely amount of nominal capacity to be used in a year would be around 374 thousand short tons.

The performance approach to estimating reduction capacity results in a much lower estimate. The peak weekly delivery of anchovies to processing plants occurred during the week of March 8, 1977, and amounted to 8,675 short tons. Because the processors routinely place nightly limits on the fishing fleet during periods of heavy fishing, it can reasonably be assumed that the plants are capable of utilizing this quantity of fish. Under ideal conditions this weekly capacity extrapolates to an annual 451 thousand short tons. Again, if the fishing season lasts 32 weeks and one week out of 4 is lost due to fishing conditions, the likely capacity of the plants, based on performance, is about 208 thousand short tons annually. Because the performance of the plants implicitly accounts for a variety of factors not considered in estimating "nominal" capacity, the performance approach must be considered more reliable. It must be noted, however, that two companies at Terminal Island, California, are reported to be upgrading their facilities so that air pollution standards do not retard the use of the plants to the extent experienced now (the dryers of the reduction plants are the primary focus of the upgrading). It is estimated that the performance-related capacity estimate could increase to around 302 thousand tons for a 32-week fishing season after the upgrading is completed.

In any case, the capacity figures represent the peak rate of processing. Because the fishing fleet does not bring fish to the reduction plants in a continuous flow, however, the peak capacity of the plants is likely to be used only infrequently. Because the weekly landings of the fleet fluctuate in response to environmental and economic conditions, the actual quantity of anchovies processed by reduction plants will always be less than the estimated annual capacity of the plants.

6.0. Optimum Yield

Achievement of the optimum yield of the fishery is central to the goal of fishery management under the Fishery Conservation and Management Act of 1976. According to the Act, the optimum yield for any fishery is the quantity of fish which equals the maximum sustainable yield (MSY) as modified by social, economic and ecological considerations such that the greatest benefit to the nation is provided. The MSY for the central subpopulation of the northern anchovy is estimated to be 484 thousand short tons per year. This figure must be treated as an estimate of the maximum annual average yield which could be taken over a period of many years. Natural variability in recruitment to the stock will not allow 484 thousand tons to be taken every year. Consideration of the trade-offs between average annual yield and the variability of yield is the principal point of section 6.1.

Ecological considerations require that the role of the anchovy as forage for predators be recognized. Section 6.2 discusses the benefit arising from the stock as a source of forage. An important social consideration is the fact that a major commercial fishery for anchovies in California, the reduction fishery, is widely unpopular among the State's recreational fishermen. Aspects of this factor are discussed in Section 6.3. Economic considerations discussed in Section 6.4 focus on the issue of economically efficient patterns of commercial exploitation. A reasonable allocation of the yield of the stock to the fishery in the U.S. FCZ is discussed in Section 6.5, and the final optimum yield formula is presented in 6.6.

6.1. Biological considerations

The most common biological criterion invoked in the fishery management field is maximum sustainable yield (MSY). This concept emerges from theoretical models of population growth which often rely heavily on the assumption of constant environmental conditions. An MSY value of 484 thousand short tons per year is estimated for the central subpopulation of northern anchovy. The theoretical model yielding this value is presented in Appendix II. While MSY is generally recognized as an average sustainable yield, the consequences of treating this average as a stable rate of yield are rarely recognized and considered to the extent that they must be with regard to the northern anchovy.

The MSY estimated for the central subpopulation of the northern anchovy is the average or "expected value" calculated from a statistical fit of a theoretical population growth curve. The data used to calculate the fitted equation were the anchovy spawning biomass estimates from the California Cooperative Oceanic Fishery Investigation (CalCOFI), a consortium of agencies including the California Department of Fish and Game, the California Academy of Sciences, the National Marine Fisheries Service, and the Scripps Institution of Oceanography. The spawning biomass estimates are the best available estimates of the anchovy biomass. The observed population levels regularly deviate from the expected values of the estimated population growth curve by as much as 50 percent. Thus, while the MSY of 484 thousand tons occurs at the equilibrium population biomass of 1.8 million tons, natural variability makes it impossible to maintain this population size. Actual sustainable yields will necessarily be smaller as sustainability becomes more rigorously invoked. In order to maximize the total yield from the stock over a long period of years, therefore, the annual yields must be allowed to vary considerably.

The technical solution to the problem of maximizing total yield over time is to specify a policy which assigns a level of catch smaller than MSY when the population is below 1.8 million tons of biomass. Similarly, the policy assigns an annual yield greater than MSY in years when population size is greater than 1.8 million tons. Algebraically, the policy is approximately as follows:

Catch = 0 if biomass < 1.45 million tons;
Catch = 1.38 x (biomass - 1.45) otherwise.

Thus a sliding scale is used to assign yearly catch according to the anchovy biomass available at the beginning of the year. Although this policy is a dynamic extension of the usual MSY criteria, it has some detrimental characteristics. Given the expected variability of the anchovy biomass, this policy would require the fishery to gyrate between tremendously large catches in some years to no catch at all in most years. It is expected that under this maximum yield policy the fishery would be shut down entirely in approximately 2 years out of 3. Clearly, the economic and social advisability of such a harvest policy is suspect. Thus the biological criterion of maximizing total fish yield from stock requires tempering. From a biological standpoint, any harvest policy should (1) maintain an average population size equal to or greater than that associated with MSY (i.e., 1.8 million tons), (2) require the annual harvest to fall below expected annual growth when the population size is less than 1.8 million tons, and (3) call for a substantial unfished reserve stock to protect against accidental depletion and ecological disasters. Any optimum yield which satisfies these conditions can be considered biologically acceptable.

Another biological consideration is the problem of unusual sex ratios in the reduction fishery catch. The disproportionate catch of female fish by the fishery could lead to a more severe impact than calculations based on equal catches predict. In essence, the reproductive potential of the anchovy population consists of the female spawning biomass, and therefore, fishery effects on this population segment are of importance to anchovy management.

6.2. Ecological considerations

The northern anchovy plays a highly important role in the ecology of California coastal waters. Food habit studies have shown it to provide the bulk of forage requirements to predatory fish and invertebrates (many of which are fished recreationally and commercially and to marine mammals and birds. Of particular interest among marine birds is the California brown pelican (Pelecanus occidentalis californicus), an endangered species. The effects of various levels of anchovy biomass are difficult to predict due to the complexity of the ecosystem and our superficial knowledge of it. A crude measure of the predator biomass supported by the anchovy can be guessed at, using mortality rates and conversion coefficients. Thus, 73% of a 4 million ton anchovy stock will be consumed by predators annually (see 4.1.6), and with anchovy protein being converted to predator protein at a 10% efficiency, that anchovy stock is supporting an estimated 292,000 tons of predator biomass. Since most predators are opportunistic in feeding habits, they could switch to alternative prey. However, there is no clear indication that equivalent alternatives exist in the ocean; most likely alternatives will be less efficient sources of nutrition. On the other hand, anchovies themselves consume large quantities of fish eggs and larvae, including their own, and may exert considerable mortality on the early life stages of their predatory fish.

It is very difficult to place a value on anchovies for their forage role in the ecosystem. The extent to which they support economically valuable resources, such as sportfish, market fish, and squid, is variable and difficult to determine. Non-valued resources such as birds and marine mammals are also largely supported by anchovies, lending further difficulty to their valuation. The conclusion which arises from these ecological considerations is that benefit to the nation occurs by leaving fish in the ocean. If the domestic fishery is unable to harvest its quota allotment for a given year, ecological benefit still occurs from the unharvested fraction.

The time series of anchovy spawning biomass estimates indicates that large natural fluctuations in abundance must be expected independently of fishery effects. The period 1951 to 1961 showed spawning biomass below 2 million tons (Appendix 1) whereas the more recent years averaged 3 to 4 million tons. There are no indications that the abundances of predatory mammals, birds or fishes declined during the earlier period, although the evidence is meager in any case. We may therefore tentatively conclude that maintaining a long-term average anchovy biomass in excess of 2 million tons should not have severe adverse effects on predators. At the same time, management should curtail the fishery when lower levels of abundance occur, allowing the resource to recover rapidly, and preventing the possibility of fishery-induced collapse of the forage base.

6.3. Social considerations

Of the California citizens concerned about the anchovy fishery, the commercial fishermen and related shore workers are numerically a small minority. The number of marine anglers in California is certainly greater than one million, and the public expressions of these anglers are uniformly against further expansion of the commercial reduction fishery. It can be fairly stated that the pressures brought to bear by the vocal members and representatives of the recreational fraternity have been largely responsible for retarding the growth of the anchovy reduction fishery in recent years. These facts alone make the anti-reduction fishery sentiment an important social factor to be considered in defining optimal yield.

Because the ecological linkages within the community of marine animals in the California Current are poorly understood, the impact of an anchovy fishery on the abundance of recreationally important fish species, birds, and mammals cannot be predicted with accuracy. It is reasonable to proceed with caution, and to attempt to evaluate the social costs of being wrong should unforeseen large ecological impacts occur.

Another consideration is the impact that fishery management has on special groups. Within the reduction fishery the two major groups are those associated with the Monterey and San Pedro fisheries. In order to assure that each of these fisheries will have a reasonable opportunity to fish, the overall reduction fishery quota should be divided into two regional quotas. Traditionally, the California State quota system sets a separate reduction fishery quota for the region north of Pt. Buchon.

6.4. Economic considerations

The primary considerations for this section are: 1) the economic contribution of the fisheries to the Nation as a whole, and 2) the economic efficiency of the fishery.

A generally accepted notion of economic contribution is net economic value -- the dollar value of anchovies to the users of anchovies and anchovy products, minus the dollar costs of harvesting anchovies and processing anchovy products. Appendix VI of this Plan considers this economic measure of value applied to the anchovy reduction fishery. Little economic data was available from the non-reduction fisheries, and no substantial economic analysis of those fisheries was attempted. The live-bait catch, however, is far more valuable per ton than is the reduction fish harvest. As indicated in Section 3.5.1.1 the live-bait anchovies are worth around $2.3 million per year. Since the annual live-bait catch is about 6,000 tons, the value per ton is a remarkable $381. Because of this relatively high value, it is reasonable to permit the live-bait fishery to continue harvesting as much as it normally harvests so long as the anchovy biomass is above some minimum level.

Small amounts of anchovies landed for use as frozen bait, canned pack, or fresh human consumption should also be given a higher priority than the reduction harvest. This is justified by their generally higher unit values, the desirability of encouraging the growth of a fishery for human food, and the savings in administrative expense. The total non-reduction fish catches in California averaged 8525 tons during the period 1970-1975, with the highest catch being 9675 tons. An amount at least this large should be reserved from the overall northern anchovy quota for use by the non-reduction fisheries.

The value of the reduction fishery is directly related to the value of the products -- meal, oil and solubles -- produced from the reduction harvest. The economic value of these products is best measured by the amount that users are willing to pay and this willingness to pay is reflected in the demand for anchovy products as discussed in Appendix VI. The costs incurred in producing the anchovy products also reflect values of products (ships, labor, fuel, equipment, and so forth) for which people are willing to pay. Thus, the net economic value is a standard economic criterion by which to judge this aspect of optimality, and it corresponds to the amount that the public is estimated to be willing to pay for the products minus the amount that is spent in the production process.

As noted in Appendix VI, an optimum economic harvest policy can be computed for a given economic situation (level of demand, costs, and capacity) and a given biological environment. The optimum policy will further be influenced by the proportion of the total annual harvest which the United States can reasonably expect to take. For three hypothetical U.S. shares of the harvest -- 100 percent, 70 percent and 50 percent -- the economically optimal harvest policies are approximated by the following quadratic equations (developed in Appendix VI):

For 100% U.S. share -

$$\text{catch} = -345477 + 0.45347\ B - 4.666 \times 10^{-8}\ B^2;$$

For 70% U.S. share -

$$\text{catch}_{U.S.} = -322892 + 0.37497\ B - 3.318 \times 10^{-8}\ B^2;$$

For 50% U.S. share -

$$\text{catch}_{U.S.} = -333399 + 0.34330\ B - 3.175 \times 10^{-8}\ B^2.$$

where B represents anchovy spawning biomass in short tons. All three of these U.S. harvest policies are illustrated in Figure 6.4-1. In determining these policies, the estimated population growth model was treated as a deterministic function. Thus there is an equilibrium maximum economic yield (MEY) corresponding to each hypothetical U.S. share of the fishery. These values are analogous to MSY in that they assume a deterministic rather than stochastic harvest policy. Thus the maximum economic yield constitutes an MSY adjusted for some economic factors. As stated in Appendix VI, Table 8, the equilibrium economic values and corresponding catches are:

	U.S. equilibrium MEY	U.S. equilibrium catch
A. For 100% U.S. share	$8,951,000	458,000
B. For 70% U.S. share	$7,003,000	327,000
C. For 50% U.S. share	$5,335,000	237,000

Because the variability of the recruitment to the anchovy population is great, these equilibrium values have little use in defining the optimum yield from the fishery in any given year. Also, the levels of demand for anchovy reduction products and the costs of producing anchovy products vary from time to time. Thus the economic yields estimated here are not precise quantities but rather reasonable guides to defining optimum yield.

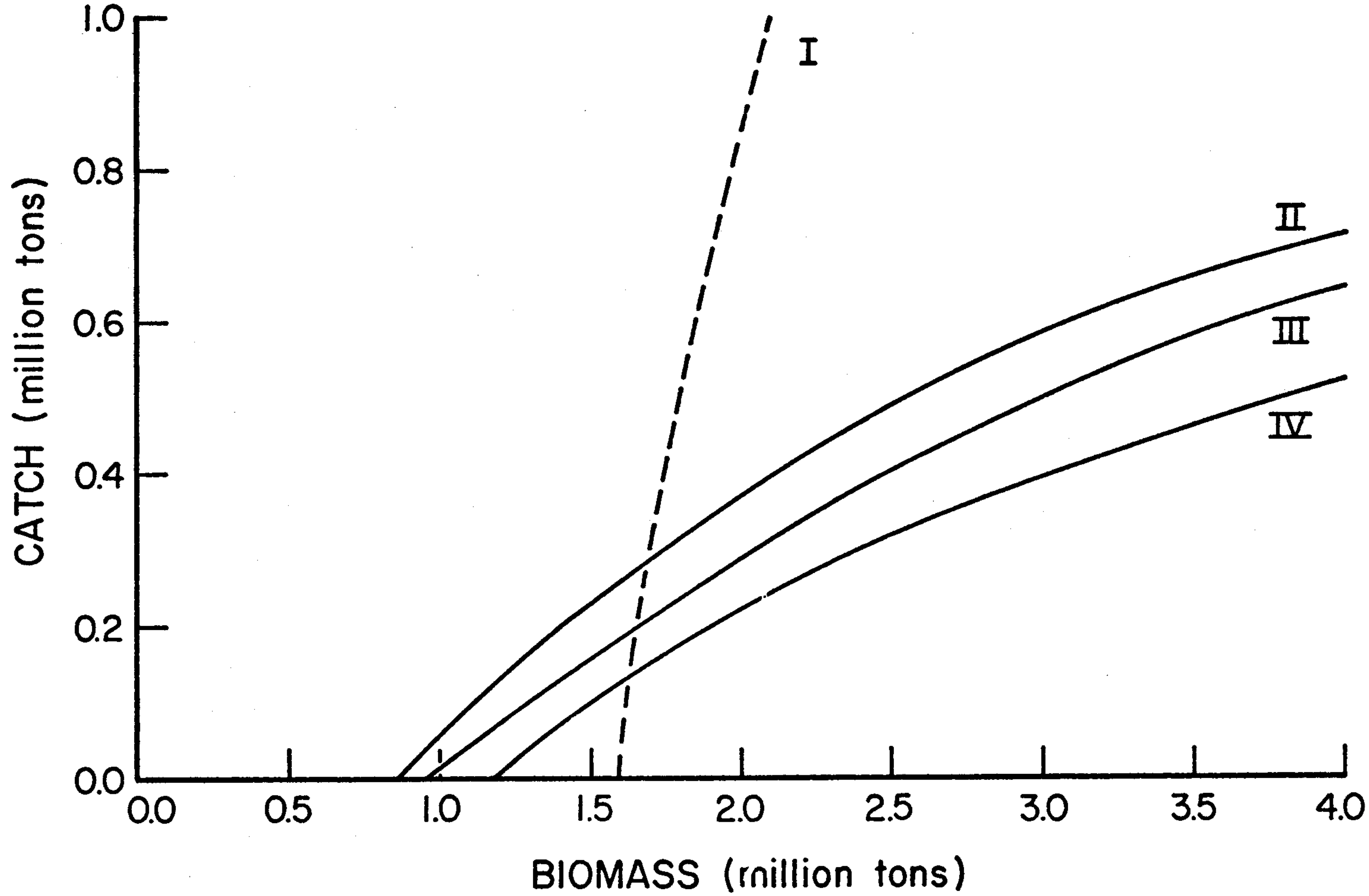

Figure 6.4-1. Optimal harvest policies for Maximum Catch Objective (I), and for the Economic Objective with 100 percent U.S. Share (II), 70 percent U.S. Share (III), and 50 percent U.S. Share (IV).

To take into consideration the variability of the anchovy stock, the optimum economic yield must vary from year to year. The stochastic (MARKOV) population model (Appendix II) was used to evaluate various harvest policies corresponding to the above MEY values. For a 70% U.S. fishery, the stochastic model predicts an average U.S. catch of about 361 thousand tons per year, and an average annual economic yield of $6.5 million. As compared to the equilibrium yield, the stochastic model harvests more on the average but is worth less due to the fact that annual yields fluctuate around the optimum equilibrium level which is a local maximum for net return based upon unit costs and demand price.

The economic values calculated for the reduction fishery need to be balanced against the non-quantified values associated with maintaining a biomass of anchovies to serve as food supply and attractor for larger fish and other predators. The value of anchovies in their role as food supply for predators would be reflected in the net contribution of anchovies to the abundance of predators. The value of increased abundance of predator fish would, in turn, be measured by estimates of increased recreational and commercial fishing values. Unfortunately, economic studies to estimate these values are just getting underway. Sufficient ecological knowledge to assess the anchovy/predator linkage is also lacking. Thus the economic evaluation of the anchovy's importance to the ecosystem cannot proceed beyond the superficial, and possibly mis-leading, statement of sales values for recreational activities. Nevertheless, the large economic impact of the recreational fisheries in California, along with the importance of anchovies for live bait, serves to justify a harvest policy which maintains a larger average biomass than does the maximum economic yield policy. Generally, this means that the harvest policy should aim for long-term average anchovy biomass of greater than 2 million short tons.

Another economic consideration is that of efficiency. Marine fisheries have a history of economic inefficiency due to overexpansion of capital investment in fishing fleets and, sometimes, in processing plants. This overcapitalization problem stems from the free competition for use of valuable common property resources (see H.S. Gordon, 1954; or J. Crutchfield and A. Zellner, 1962). Management policies geared solely to restrictions on catch through quotas, size limits, gear restrictions, season closures, and/or area closures cannot address the problem of overcapitalization. Examples of how traditional fishery management methods frustrate attempts to achieve economic efficiency are well documented in the cases of Pacific salmon and Pacific halibut (see Crutchfield and Zellner, 1962). In both cases, catch limitations and gear restrictions, in the absence of limits to access by commercial vessels, led to excessive competition for allowable harvests. More and more vessels entered these fisheries over time, leading to shorter and shorter fishing seasons, excessive congestion on some fishing grounds, and difficult management control problems.

Theoretically, the competitive expansion of the commercial fishing fleet and processing facilities is expected to continue until investment capital earns a rate of return just equal to the going rate of return earned in alternative lines of endeavor. The optimum level of capitalization, however, occurs when investment in fishing and processing capacity leads to a maximum expected net economic value. An analysis of the optimum fishery capacity for the anchovy reduction fishery is presented in Appendix VI. Assuming that the United States is given a 70% share of the annual allowable harvest, for instance, the optimum catch capacity for the international fleet would range from 420 to 560 thousand short tons annually, depending upon the harvest quota policy adopted and upon the demand and cost conditions assumed.

Under free competition for fish (i.e., with no restrictions on entry of new capital) the fishing fleet can be expected to expand up to 720 to 800 thousand short tons annually. From a social standpoint, the investment of additional capital which increases the fishing capacity from the optimum level to the competitive level is a waste of scarce resources. The estimated potential economic waste is in the range of 3.5 to 6.8 million dollars.

To prevent the fishing industry from developing the excessive investments in fishing and processing capital, fishery economists have typically prescribed limited entry regulations. These measures can take a variety of forms, including (1) license limitations, (2) individual fishermen quotas, and (3) auctions for rights to fish. Clearly, any method of limiting access to the fishery will have social and cultural impacts as well as economic efficiency benefits. Foremost among these impacts is the loss of some personal freedoms which are often very strongly felt among communities of independent fishermen. It may become impossible, for instance, for the fishermen to bring their offspring into the fishery as they may want to do. Other public resource management programs, such as national forest management and offshore petroleum development, have auctioned off permits to exploit natural resources. But these industries are, of course, more highly industrialized and do not seem to have the cultural characteristics of the marine fisheries.

As noted in Section 5.0, the existing U.S. anchovy fishing fleet is capable of harvesting around 247 thousand tons assuming that recent past fishing conditions and patterns persist. Fish meal processing capacity, under the same assumptions, is probably about 226 thousand tons in the United States. Because of market conditions and reduction fishery quotas, the fishery has never taken more than 163 thousand tons in any year. The Mexican anchovy fishery in Baja California has taken 130-150 thousand tons of anchovy and is in the process of expansion. Assuming that the Mexican capacity increases to 200 thousand tons in the near future, a total of around 450 thousand tons of fishing capacity will be available to exploit the central subpopulation of anchovies. Some unknown proportion of the Mexican fishing effort is applied to the southern subpopulation of northern anchovies.

At present, therefore, the fishing capacity does not exceed the upper bounds of the range of estimated optimum economic capacity. As a result, the limitation of additional investment is not seen as a critical need in 1978. Nevertheless, consideration of limited entry as a means to prevent rapid accumulation of excessive reduction fishery capital is a serious need for the future.

6.5. Optimum yield in the U.S. Fishery Conservation Zone

Because the northern anchovy's central subpopulation inhabits waters off both Mexico and the United States, it is necessary to consider what portion of the overall optimum yield from the subpopulation should be taken in the United States FCZ. Ideally, an allocation of an overall fishery quota should be agreed upon by the two countries. In the absence of a ruling international agreement on this allocation, the Fishery Management Plan must contain an interim formula for determining the United States' portion of the optimum yield. Without such an interim measure the optimum yield for the U.S. fishery would remain undefined.

It is reasonable to adopt a U.S. allocation of the optimum yield based upon the distribution of the fish in the 200-mile fishery zones of the two nations. An estimate of the proportion of the central subpopulation occurring in U.S. waters can be based upon the proportion of anchovy larvae found in U.S. waters during egg and larvae surveys. As noted in Appendix VII, the estimated proportion of the stock occurring to the north of the U.S.-Mexico boundary varies substantially from year-to-year. The estimated percent of the fish on the U.S. side of the boundary has been as low as 45 percent and as high as 86 percent. The average is 70 percent.

6.6. Optimum yield formula

In view of the biological, ecological, social and economic considerations reviewed above, the optimum yield from the central subpopulation of northern anchovies is a quantity which varies from year-to-year in response to environmentally caused fluctuations in anchovy spawning biomass. Due to the importance of anchovy as a live bait, and as a component of the food supply for predator fish, birds, and mammals, the harvest of anchovies for reduction to fish meal, oil and solubles should be prevented when the population spawning biomass falls to a low level. Also, the average biomass level expected to occur under the Fishery Management Plan should be large enough to support abundant predator populations. These criteria are satisfied by the following summary statement of optimum yield.

(1) When the estimated spawning biomass of northern anchovies in the central subpopulation is less than 100 thousand short tons, the optimum yield is zero.

(2) When the estimated spawning biomass is greater than 100 thousand but less than one million short tons, the optimum yield is 18 thousand short tons for non-reduction fishery catch.

(3) When the estimated spawning biomass is 1 million short tons or greater, the optimum yield for both reduction and non-reduction fisheries is 18 thousand tons or one-third of the biomass in excess of 1 million tons, whichever is greater.

Because an average of 70 percent of the central subpopulation of northern anchovies is found in the United States' FCZ, the optimum yield within the FCZ is equal to 70 percent of the optimum yield for the central subpopulation as a whole.

7.0. Total Allowable Level of Foreign Fishing (TALFF)

Foreign fishing for anchovies in the United States' Fishery Conservation Zone (FCZ) must be governed by the provisions of PL94-265. TALFF in the U.S. FCZ is the annual optimal yield for the U.S. FCZ minus the amount that will be harvested by U.S. vessels. Because both the optimum yield and the U.S. capacity will vary from year to year, the TALFF must be re-computed annually also.

8.0 Management Regime

8.1 Objectives and Operational Needs

The objectives to be achieved by management measures adopted under this fishery management plan are:

(1) to prevent overfishing of the central subpopulation of northern anchovy (Engraulis mordax) within the United States' Fishery Conservation Zone, and waters under Mexican jurisdiction;

(2) to allow a fishery for anchovies within the U.S. Fishery Conservation Zone, and to limit such a fishery so as to achieve the optimum yield on a continuing basis;

(3) to maintain an anchovy population within the U.S. Fishery Conservation Zone of sufficient size to sustain adequate levels of predator fish, birds and mammals;

(4) to avoid conflicts between U.S. recreational and commercial fishers;

(5) to promote efficiency in the utilization of the central subpopulation of anchovies within the U.S. Fishery Conservation Zone.

In order to achieve the management objectives there are a group of operational needs that will have to be met regardless of which particular management measures are chosen from among the optional measures discussed below. These are:

(1) A U.S. monitoring and implementation scheme which:

a. sets the annual quota and closes the fishing season when the quota has been filled;

b. monitors the fish catch and the size distribution in the catch;

c. estimates the anchovy spawning biomass each year; and

d. estimates the capacity and extent to which the U.S. fishery will take the optimum yield annually.

(2) Enforcement procedures for:

a. surveillance of fishing vessels to assure compliance with area and season closures; and

b. surveillance of landings to assure compliance with size limits and sex ratio.

(3) Scientific research to:

a. improve the accuracy of the bioeconomic model underlying the management plan; and

b. develop a more cost-effective system for estimating the spawning biomass.

(4) A workable, interim, unilateral harvest policy for use by the U.S. managers until a cooperative anchovy management system is negotiated with Mexico.

(5) A cooperative management agreement with Mexico which includes:

a. an agreed common annual harvest quota policy; and

b. a fishery monitoring system which provides consistent data from both the U.S. and Mexican fisheries and facilities:

1. monitoring of annual landings; and

2. separation of catches from southern and central subpopulations.

(6) A system for reviewing and revising the Anchovy Management Plan when one of the following occurs:

a. a bilateral agreement with Mexico is signed;

b. a documented change in the anchovy population response to exploitation occurs;

c. management plans are adopted for other southern California pelagic fisheries which affect the operation of, or value of, the anchovy fishery;

d. a substantial anchovy fishery for human consumption develops;

e. the sardine population grows to the extent that incidental catches of sardines in anchovy harvests become significant;

f. a scientifically documented adverse impact of the commercial fishery on the abundance and/or availability of live bait and predator fish; and

g. an adverse impact of the anchovy fishery on other species of animal or plant life, especially those listed as endangered or threatened, is scientifically documented.

8.2. Areas, Fisheries and Stocks Involved

The stock involved is the central subpopulation of the northern anchovy which ranges from approximately 38°N, north of San Francisco, to 30°N, Punta Baja, Baja California, Mexico and as far as 200-300 miles offshore as described in section 3.1. The management regime must include this entire area. This will eventually require a bilateral agreement with Mexico and will require consistent management within both the 0-3 mile zone under California State jurisdiction and the 3-200 mile zone.

Both U.S. and Mexican fleets fish anchovies in their respective waters. The fleets consist of round haul commercial reduction vessels predominantly, and to a lesser extent, live-bait fishing vessels. The U.S. domestic fleet, as described in section 3.5.2, fishes for reduction purposes out of Moss Landing, Oxnard and San Pedro. The expanding Mexican fishery with homeport in Ensenada, B.C., fishes along the coast from Coronado Islands to Cape Colnett. The Mexican fishery also harvests the southern subpopulation. The live-bait fishery, using lampara nets, operates nearshore predominantly in southern California from Santa Barbara to San Diego. There is also an anchovy live-bait fishery that supplies recreational fisheries in Ensenada.

8.3 Management Measures - Options Considered

The management measures considered by the Pacific Fishery Management Council are discussed throughout section 8.3 A summary of the management options is presented in Table 8.3-1.

The discussion of optimum yield in section 6.4 suggested that the reduction fishery is somewhat less valuable per unit of harvest than the non-reduction fisheries (i.e., fishing for live bait, dead bait, and for human consumption). Under 1978 economic conditions, it is unlikely that the live-bait catch or the other non-reduction fishery catches will expand significantly. Also, it is noted that the non-reduction anchovy harvests are small in comparison to the reduction fishery harvests. To assure the continuation of the non-reduction fisheries and to minimize the administrative cost of managing the minor non-reduction components of the anchovy fishery, the following general policies were considered:

Management of non-reduction fisheries -

No specific management restrictions are to be applied to fisheries for northern anchovies providing live bait, dead bait, fresh fish for human consumption, or fresh fish for canning unless the combined annual harvest of these fisheries exceeds 12,000 short tons. If the non-reduction fisheries expand so that the annual harvests exceed 12,000 tons, the reduction fishery quota will be decreased by an amount equal to the expected non-reduction catch in excess of 12,000 tons. If the anchovy biomass has fallen so low that no reduction fishery is allowed, then the non-reduction catch should be held to 12,000 short tons or less. The live-bait fleet should get first priority in allocating this catch.

Management of the reduction fishery -

To conserve the northern anchovy population and to assure the optimal utilization of the northern anchovy resource, various regulations must be imposed upon the fishery providing anchovies for reduction. Optional management measures for the reduction fishery are discussed in sections 8.3.1 through 8.3.6.

8.3.1. Fishing Seasons

Rationale: Closure of seasons for all anchovy fishing, or for some types of anchovy fishing, can be utilized to strengthen management control over total annual harvests or to assist in attaining other objectives of management. Existing California regulations prohibit fishing for delivery to reduction plants during the period from May 15 to August 1 in the northern permit area (north of Point Buchon), and from May 15 to September 15 in the southern permit area (south of Point Buchon). These reduction fishery closures eliminate to a large extent the possibility of commercial purse seiners and recreational vessels being in direct physical conflict and they also reduce the possibility of conflicts between reduction and bait fishermen during periods of peak demand for live bait. The southern permit area is the area of most intense commercial fishing for reduction and is also the area of most intense fishing for the live bait and for the fish species most likely to be dependent upon anchovies for forage. In the northern area, the commercial fishery for reduction is much smaller, and the summer peak recreational fishing season is less in conflict with the commercial fishery.

Because the reduction fishery has rarely approached its annual landings quota prior to the season closure date, the season, rather than the quota, has acted as a restraint upon anchovy harvests as well as a means to avoid recreational/commercial conflicts. The closed summer period may be a period of potentially productive commercial fishing. The Mexican fishery achieves its peak harvest rates in the summer, but the lack of U.S. experience during the summer leaves unknown the question of whether the reduction fishery would be very successful in California in summertime. This fact, together with the known difficulties in catching anchovies during poor weather and peak spawning activity in the winter, suggests that the current season structure reduces the productivity of fishing vessels in the anchovy reduction fishery. Finally, the oil yield of anchovies is especially low during the months of January, February, March and April (see Figure 4.1-1.). The lower yield of oil reduces the commercial value of a ton of anchovies during the winter and early spring.

The magnitude of the sacrifice of commercial value due to the summer season closure is unknown, but potentially substantial. The options concern the extent to which season closures should be imposed in order to minimize conflicts involving recreational fishers and live-bait fishing vessels. Also, to a largely unknown extent, the summer closure may help to maintain anchovy densities in the intense recreational fishing grounds in southern California.

The socio-economic concerns of the various interest groups are summarized as follows:

Live-Bait and Recreational Fishers are opposed to extension of the reduction fishery into the summer months. The period beginning May 15 is believed by live-bait fishers to be critical to meeting bait supply commitments for the coming summer. If the summer season is to be opened to reduction fishing, the recreational fishers would prefer that this occur in the later summer rather than in the early summer.

The Reduction Fishers and Processors are willing to forego fishing during the poor months of February and March in exchange for opening the summer months to the end of June. There is relatively less industry interest in opening the period July to mid-September since other more lucrative species such as bonito and bluefin tuna become targets of the fleet. Higher oil yield occurs during the late summer, increasing the economic value of fish harvested at this time.

Option 1. Retain the California reduction fishing seasons: August 1 to May 15, north of Pt. Buchon and September 15 to May 15, south of Pt. Buchon.

Option 2. No closed season.

This option maximizes the domestic harvesting capacity without requiring additional vessels and equipment. Considerable conflict with recreational and live-bait fishers would be likely, particularly during the summer months.

Option 3. Open season is September 15 to January 31, and April 1 to June 30 in the south, and similar but beginning August 1 in the north.

Option 4. In combination with any of the season closure options, the closed season applies only to reduction fishing within the Catalina channel. Catalina channel is the area landward of a line running from Pt. Dume to the west end of Santa Catalina Island, along the coast of Santa Catalina Island to the east end, and then to Dana Pt.

Table 8.3-1. Summary of Management Options Considered

	Options			
8.3.1. Fishing Seasons Open Season	1. (California Plan) August 1 to May 15 in north; September 15 to May 15 in south.	2. No closed season	3. September 15 to January 31, and April 1 to June 30 in south; beginning August 1 in north, otherwise similar.	4. Any of options 1 through 3, but season closure not applying to reduction fishing outside Catalina channel.
8.3.2. Area Closures	1. (California Plan) Five areas of closure beyond 3-mile limit.	2. Re-evaluate the five areas of closure independently (see text).	3. No reduction fishing within 6 miles of mainland shore south of Pt. Conception.	
8.3.3 Size Restrictions	1. (California Plan) Minimum size for reduction is 5 inches.			
8.3.4. Limited Entry	1. (California Plan) No limited entry.	2. Permits for all current anchovy fishing vessels which may be subsequently transferable.	3. Two-tier permit system. Many permits for vessels with small catches; restricted number of permits for vessels taking large annual catches.	
8.3.5. Sex Restrictions	1. (California Plan) No modification of quota (not recommended unless total CFG Plan is adopted).	2. Reduce total quota by 21%, quota applies to both sexes.	3. Divide quota in half, quota applies to female fish only.	
8.3.6. Harvest Quotas	1. (California Plan) Quota is 1/3 of spawning biomass in excess of 1 million tons, but not to exceed 450,000 tons.	2. Quota is 1/3 of spawning biomass in excess of 1 million tons.	3. Quota is 1/5 of spawning biomass in excess of 0.5 million tons.	4. Quota is 1/10 of spawning biomass if spawning biomass is over 1 million tons.
	5. Quota is 1/4 of spawning biomass if spawning biomass is over 1 million tons.	6. Quota is 1/3 of spawning biomass in excess of 0.5 million tons.		
Non-Reduction Fishery (live-bait, dead-bait, fresh fish and fish for canning).	Management measures 8.3.1 through 8.3.6 do not apply to non-reduction fishery. If annual harvest of non-reduction fishery exceeds 12,000 short tons, the reduction fishery quota would be reduced by excess over 12,000 tons. *			

*The measures actually adopted modify this treatment of the non-reduction fishery by including the non-reduction catch within the harvest quota.

8.3.2. Area Closures

Rationale: Historically, the main purpose of area closures has been to minimize conflicts between reduction fishing activities and bait and recreational fishing activities. The inshore zone is generally populated by smaller anchovies and is the favored region for live-bait fishing due to the necessary shallow-water conditions. The inshore region is also the area where most of the game fish reside and where most sportfishing activity takes place.

The State of California has jurisdiction within 3 miles of shore, including both the mainland and islands. Under the FMCA, the Federal Government has fishery jurisdiction from 3 to 200 miles (FCZ). Coordination between Federal and State management is essential to effective implementation of area closures.

Recent evidence from NMFS recruitment studies and CF&G sea surveys in the near shore zone indicate the 3-mile inshore zone is a major habitat of pre-recruit anchovies (Section 4.1.5 and 4.5).

The present State closure of the 3-mile inshore zone in the southern permit area south of Pt. Buchon is a step toward achieving objectives 3 and 4. As long as the current harvest in the northern permit area continues to average about 5,000 tons per season and less than the 15,000 ton historical allocation, closure of this 3-mile inshore zone by the California Fish and Game Commission is unlikely. There are also five separate area closures that extend beyond 3 miles that give added protection to the live-bait industry and predator forage supplies. The existing California area closures are summarized in Section 3.3.2, Appendix III and in Figure 8.3-1. The existing state closures either prohibit anchovy fishing activity in the specified area or prohibit the use of particular types of fishing gear. All but one of the gear closures are totally inside 3 miles. This exception is the Santa Monica Bay closure.

Existing closed areas that require Council evaluation are those areas that extend beyond the 3-mile zone. These are: (1) the large area closure off San Francisco Bay in central California that extends from Pt. Reyes (Marin County) to S. Farallon Island and to Pigeon Point (San Mateo County); (2) the small area of Oxnard that extends offshore 4 miles from the mainland shore between lines running 235° magnetic from the steam plant stack at Mandalay Beach and 205° magnetic from the steam plant stack at Ormond Beach; (3) Santa Monica Bay from Malibu Point to Rocky Point (Palos Verdes Point); (4) the area outside Los Angeles Harbor described by a line extending 6 miles 165° magnetic from Point Fermin and then to a point located 3 miles offshore on a line 210° magnetic from Huntington Beach pier; and (5) the Oceanside to San Diego zone, 6 miles from the beach that begins at Oceanside Harbor and extends to the U.S.-Mexico border.

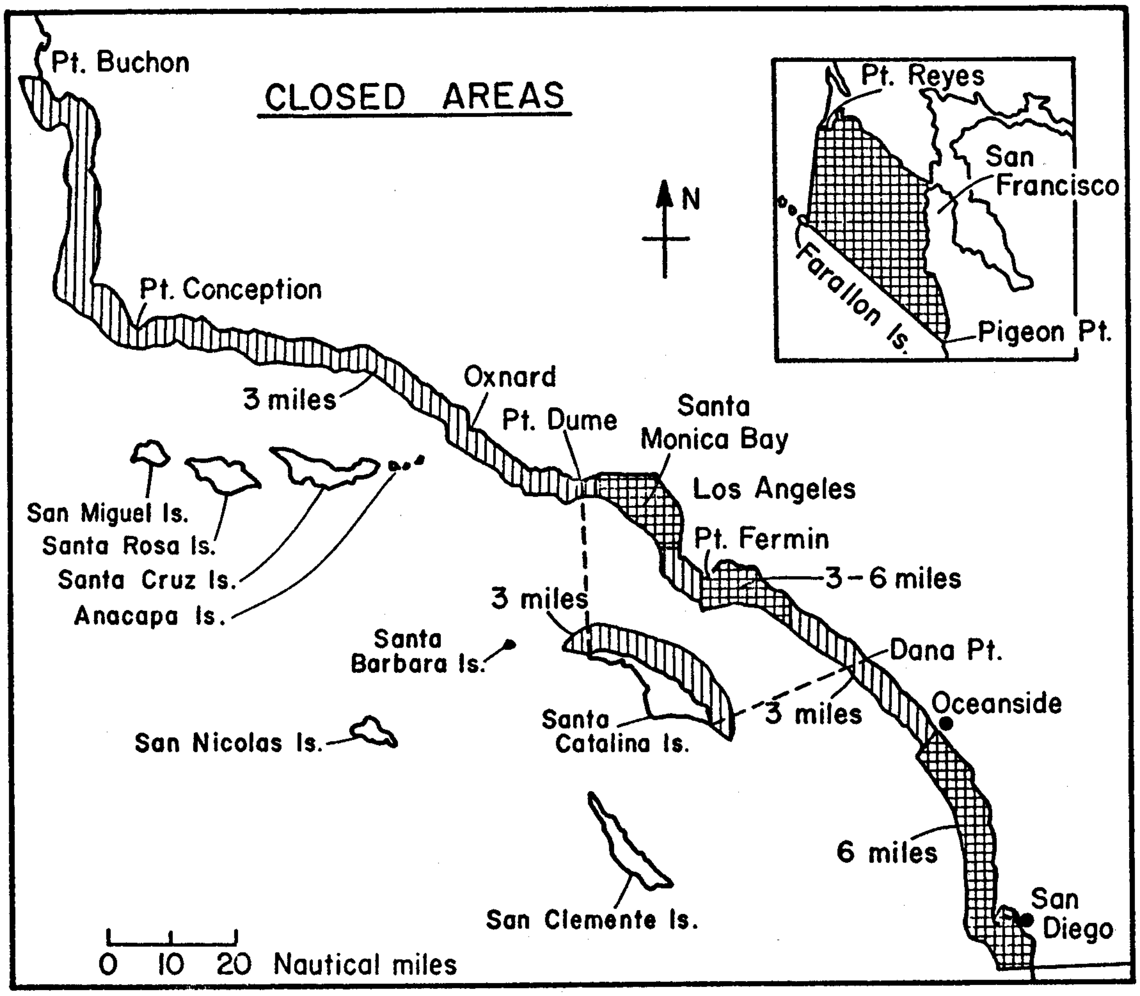

Figure 8.3-1. Existing California area closures, and optional Catalina Channel closure (outlined by dashed lines).

Option 1. Retain existing California area closures that extend beyond 3 miles from shore.

These area closures have evolved over the years from debates between recreational and commercial user groups over use of the fishery resources. In general, the area closures provide sanctuaries that act to reserve anchovies that may enter the closed area for live bait in the traditional baiting grounds, and for forage for various predator species some of which are of recreational importance. The pre-recruited anchovies are given some further protection from exploitation by the reduction fishery. In addition, these closed area reduce chances of direct confrontation between commercial and recreational fishermen on the fishing grounds.

Option 2. Consider separately the five area closures that extend beyond 3 miles from shore.

A. Farallon Island Closure

The Farallon Island closure off San Francisco Bay in the northern permit area discourages commercial anchovy fishing for reduction by making travel distances excessive for a processing industry operating out of San Francisco Bay. This preserves the anchovies in the area for forage for such species as salmon and striped bass. A fishery in the area would exploit both northern and central subpopulations. It is questionable whether sufficient supplies of anchovies would be available to sustain a long term fishery in this area.

B. Oxnard Closure

The small area closure off Oxnard or Port Hueneme reserves a portion of the traditional baiting grounds for the live-bait fishery.

C. Santa Monica Bay Closure

The traditional Santa Monica Bay closure prohibits commercial net activity in general in the densely populated region of Los Angeles. Santa Monica Bay is a major area for recreational fishing and making bait. Modification of this closure that would allow commercial fishing for other than live-bait would be opposed by a large number of citizens living in the Los Angeles area.

D. Los Angeles Harbor Area Closure

The area closure outside of Los Angeles harbor prohibits the harvesting of anchovies for reduction on the shallow banks and flats that would otherwise be heavily fished because of the area's proximity to the fish processing plants where the majority of the anchovies are unloaded. This reserves the area for the live-bait fishing.

E. Oceanside to San Diego Closure

The 6-mile closure from Oceanside to San Diego was set aside to reserve anchovies that might enter the area for forage and bait. In the early years of the anchovy reduction fishery, this closure may have deterred the development of a reduction fishery in San Diego area. At present, the reduction fishery seldom ventures that far south. Currently, there are two tuna canneries in San Diego with reduction facilities for tuna offal. They have potential capabilities to manufacture anchovy meal and oil with only minor modification in facilities.

Any modifications to these five area closures will require that the director of California Department of Fish and Game take action to conform state law or Commission regulations to the anchovy management plan (see Section 3.3.1.1 and Appendix III).

Option 3. Uniform 6-mile closure to reduction fishery.

No anchovy fishing for reduction purposes would be allowed within 6 miles of the mainland from Pt. Conception to the Mexican border.

8.3.3. Size Restrictions

Rationale: The population growth model (Appendix II) indicates that harvest of pre-spawners results in a lowered equilibrium yield curve. Also, immature fish presumably produce less oil upon reduction, and are therefore less valuable.

A minimum size limit that protects the pre-spawners will promote optimum utilization of the resource with respect to Objective 2. Since pre-spawners generally inhabit the nearshore area where they provide forage for predator species and are available to the live-bait fishery, a minimum size limit further supports Objectives 3 and 4 (maintaining sufficient forage supply and avoiding conflicts between the reduction and recreational fisheries).

Option 1. Fish shorter than 5" total length may not be purchased except for use as bait, with a 15 percent by weight incidental catch allowance.

This option is identical to existing regulations in Title 14 of California Fish and Game Commission. The fishery is accustomed to abiding by this regulation, and there is no reason to modify it.

8.3.4. Limited Entry

Rationale

There are two reasons for considering a limited entry program for the northern anchovy fishery. The first is economic efficiency, and the second is administrative control. Economic efficiency dictates that the amount of capital equipment and labor devoted to the annual harvest of anchovies be the minimum amount necessary. If this efficiency is attained, then the fishery will contribute the maximum possible dividend to the national income. In section 6.4 of this Plan, it was explained that, unlike most free enterprise industries, fisheries do not generally attain a reasonable level of economic efficiency. While competing freely for a common property resource, the private firms engaged in a fishery tend to invest more than is necessary to catch the available yield in fishing vessels and gear. A limited entry (or limited access) program attempts to restrain over-investment (or overcapitalization) in the fishing industry. Also, administrative control should be facilitated somewhat by a limited entry program. When the size of the fishing fleet being regulated is held within reasonable bounds, it should be easier and less costly to monitor and enforce fishery regulations.

The Fishery Conservation and Management Act of 1976 includes limited access systems as a discretionary provision of a Fishery Management Plan (see Section 303(b)(6)). The Act requires that, in the development of such systems, the Council and the Secretary take into account -

"(A) present participation in the fishery,
(B) historical fishing practices in, and dependence on, the fishery,
(C) the economics of the fishery,
(D) the capability of fishing vessels used in the fishery to engage in other fisheries,
(E) the cultural and social framework relevant to the fishery, and
(F) any other relevant considerations."

The options for limited entry systems presented below take into account items (A) and (B) by allowing all current and recent past participants to continue fishing for anchovies.

Item (C), the economics of the fishery, is discussed at length in section 3.5 and Appendix VI. Two important points derived from these discussions are (1) that economic efficiency in the fishery promotes higher profits for fishermen and a greater net economic contribution to the national economy, and (2) that the optimum level of investment in the anchovy reduction fishery must be defined such that the expected net economic return to the nation be as large as possible. The limited entry consideration itself is a means of addressing the first point. In determining the optimum level of investment, the optional measures take into account the fact that fluctuating annual yields from the fishery will be experienced. Thus, the upper limit to be applied to the anchovy fishing fleet must allow a level of domestic harvest capacity sufficient to take the largest annual catches that are economically justified under the harvest quota policy. As estimated in Appendix VI, the optimal levels of fleet capacity under each of the harvest quota options are:

Harvest Quota option	Estimated Optimum Catch Capacity Assuming - A 70% U.S. share (1000 short tons)	Estimated Optimum Catch Capacity Assuming - A 50% U.S. share (1000 short tons)
Option 1	420-450	450
Option 2	420-580	470-690
Option 3	400-560	440-630
Option 4	345-475	360-510
Option 5	380-550	440-570
Option 6	390-540	430-620

Another important factor is economic equity. A limited entry program will, if successful, create a source of real economic profit that would not otherwise exist. By vesting the right to fish in the ownership of licensed anchovy fishing vessels, a limited entry system assigns a portion of the potential economic profit to the vessel owners. This raises the question of whether or not it is equitable or socially appropriate to enhance the private economic welfare of individual vessel owners through a public fishery management program. The FCMA does not allow the Secretary of Commerce to collect from licensed fishermen fees which exceed the administrative cost of issuing fishing permits. Under this restriction, any limited access system can be expected to create profits for the fishing industry. The equity implications must be considered in setting up a limited access system.

Item (D), the capacity of anchovy vessels to engage in other fisheries, is noted in section 3.5.2.1. of this Plan. The limited access systems proposed here will not restrict the licensed anchovy vessels from participating in other fisheries. The other fisheries in which anchovy fishing vessels participate to the greatest extent are those for bonito, jack mackerel, and tuna. This situation can be taken into account in setting the upper limit of anchovy reduction fleet size by considering many of the anchovy vessels as part-time. Thus, the total licensed fleet must be large enough to take the maximum economically justified anchovy harvests while still maintaining the appropriate levels of harvest in the other fisheries. The capacity limits suggested above are high enough to assure adequate fishing capacity under reasonable circumstances. If future developments, such as a great expansion in the jack mackerel fishery, result in a shortage of total capacity then the licensed fleet could be enlarged. To accurately predict the total future fleet capacity needed to harvest all of the fish species is impossible. Flexibility in adjusting the limited number of anchovy fishing licenses in the future would minimize the possibility of causing a shortage of fishing capacity.

In response to Item (E), the proposed limited entry options are not expected to include any radical changes in the social and cultural institutions of the affected fishing communities in San Pedro, Oxnard and Monterey, California. In particular, the establishment of licenses for anchovy vessels is not expected to interfere with the independent, private enterprise nature of the fishing communities. No other relevant considerations have been identified for Item (F).

Option 1. No restrictions on the number or types of vessels fishing for anchovies for any purpose.

Option 2. Issue a limited number of licenses for the anchovy reduction fishery. No limits to be placed upon the non-reduction fishery. Reduction fishery licenses are to be vested in the ownership of the licensed vessels and can be transferred to another vessel owner by sale.

This option accomplishes the objective of putting an upper limit on the size of the fishing fleet without imposing any economic sanctions or taxes. One drawback to the option is that it does not prevent overcapitalization of the fleet through upgrading or replacement of vessels. That is, a limited number of vessels could be vastly improved through additional investments in existing vessels and through the retirement of smaller, less productive vessels and their replacement with larger, more valuable vessels.

Option 3. Issue a limited number of anchovy reduction fishing licenses within a two-tier system distinguishing between vessels with small, infrequent landings and vessels landing large volumes of fish. Licenses would be vested in vessel owners and would be transferable.

The key to this option is that it allows a large number of licenses to be issued so that all vessels with a history of anchovy reduction fishing can be licensed. At the same time, a substantial replacement of small vessels with large vessels would be forestalled by the two-tier system. The smaller vessels would be issued first-tier licenses with a specific annual catch limitation of 250 tons. Initially, no restrictions would be put on the number of such licenses to be issued. All vessels applying for the catch-limited permits would be accommodated.

All vessels with a history of landing anchovies for reduction in California in quantities of more than 250 tons annually would be issued the second-tier permits. In addition, a number of permits would be allowed above the number of existing large reduction fishery vessels. In 1977, the number was about forty-five. The total number of these licenses issued would depend upon the fishing season closures and the harvest formula adopted for the final Anchovy Management Plan. Generally, the number of licenses allowed should be large enough to assure that the licensed fleet could harvest the maximum annual harvest expected to occur under the harvest formula adopted.

As an example of how this would work, suppose harvest Option #2 is chosen and the 32-week reduction fishing season (September 15 to May 15) is retained. According to the analysis in Appendix VI, the maximum level of harvest which would be economically optimal under this option is about 300 thousand tons for the U.S. (assuming Mexico takes 30 percent of the quota). In Section 5.1 it was estimated that the current fleet could probably catch 247 thousand tons of anchovies in the 32-week season if the processing capacity were not constraining. These two facts indicate that an additional fishing capacity of 54 thousand tons annually could be licensed. If the new licenses were to operate medium-size purse seiners capable of taking 10,000 tons of anchovies during the season, then the number of additional reduction fishery licenses would be 5-6. Adding this to the existing 45, the total licensed fleet in the second-tier would be 50-51.

The actual limit to the second-tier licenses would have to be calculated for the final harvest formula and season closure adopted in the Plan. Also, the issue of optimal fleet size would remain open to additional research findings or considerations in the future.

The initial distribution of second-tier licenses will be made to vessels that have held anchovy reduction fishing permits from California Department of Fish and Game during one or more of the three years preceding September 15, 1977. Other vessels will be issued permits on the basis of demonstrated capability to catch anchovies.

8.3.5. Sex restrictions

Rationale: The ratio of females to males in the anchovy reduction fishery is a concern, because the female portion of the fish population represents the spawning potential. In making the spawning biomass estimates and in estimating the population growth equation, it is assumed that there are equal numbers of females and males (in the population as a whole). This assumption is supported by the sex ratios in midwater trawl samples taken during CF&G sea surveys (see Table 4.1-5). Despite the presumed numerical equality of females and males in the population, the San Pedro reduction fishery tends to take a disproportionate amount of female fish (see Table 4.1-3). Thus the harvest of anchovies by the reduction fishery should be regulated on the basis of spawning potential taken (i.e., amount of female fish caught) rather than on the basis of total tonnage taken. Modifications to the quota formula based on sex ratio in the catch can accomplish this. Options 2 and 3 represent two possible modifications to the annual catch quota.

It is very unlikely that the average sex ratio in the San Pedro reduction fishery landings (1.73:1) represents the true sex ratio in the anchovy population as a whole. Theoretical considerations and the aforementioned sea survey results strongly suggest that the population sex ratio is very close to one-to-one. However, if the commercial landings sex ratio were representative of the population sex ratio, then an adjustment to the annual quota formula would still be necessary. If, for instance, the true ratio of females to males in the anchovy population is 1.73:1, then the biomass is 21% less than the biomass estimates based on larva censuses using 1:1 sex ratio. Furthermore, the population growth potential is 21% less than that estimated by the equilibrium growth curve (see Figure 4.7-2). If this were the case, then the annual quota formula would have to be modified in much the same fashion as it would when there is a one-to-one sex ratio in the population and a 1.73:1 sex ratio in the commercial catch.

Option 1. No sex restriction as in existing California plan. This option is included in order to allow the existing California plan to be adopted, if the Council wishes. If any other harvest quota formula is chosen, this option should not be chosen, since the fishery harvests mostly female fish, decreasing the productivity of the resource.

Option 2. Based on observed average sex ratios in the San Pedro fishery (1.73 females to 1 male, by weight), the quota for any year will be reduced by 21% from the value given by the harvest formula in section 8.3.7 (catch quotas).

This option corrects for the sex ratio problem on the average, but does not allow for more catch if the ratio is lower, or for less catch if the ratio is higher in any given year. It does have a finite point at which the quota is filled. The present CF&G catch sampling program would be sufficient to implement this option, should it be chosen.

<u>Option 3</u>. The quota for any year will be filled when 50% of basic quota has been landed in female fish, as determined by monitoring of landings.

This option allows the actual catch to increase if more male fish are landed, or to decrease if more female fish are landed. Since the sex ratio directly affects the total catch, there would be some incentive for the fishermen to avoid taking female fish if possible. If fishermen were to actively seek a larger proportion of male fish, they would shift fishing to outside of the San Pedro Channel, within which anchovies are predominantly female. Such a shift in fishing grounds would be favorable to bait and recreational fishing interests, who would prefer less anchovy fishing in the San Pedro Channel. Of course, such fishery effects are conjecture and would remain to be proven. A disadvantage of the option is the lack of a finite total catch at which the fishery would close, if only male fish were being landed.

8.3.6. Harvest Quotas

Rationale: The resource can be expected to fluctuate in biomass under any level of fishing pressure. Allowable levels of harvest must reflect the current status of the stock, so that a margin of growth is allowed when the biomass is low, and so that greater quantities may be harvested when the biomass is high. In the case of the anchovy fishery, we can establish a harvest quota formula such that the quota is determined by the most current biomass estimate. Each of the formulas considered is for the anchovy reduction fishery only. The live-bait, frozen-bait and food-fish harvests are allowed to continue at, or slightly above current levels without further restrictions unless the non-reduction harvest exceeds 12,000 short tons per year. Also, it is important to consider the Mexican fishery for anchovies and the practical difficulties that this fishery poses for the interpretation of the harvest formulas. Because the biological basis of the optimum yield discussion is the stock of fish which is exploited by both the United States and Mexico, the harvest formulas represent the total annual harvest by both nations. Until a bilateral agreement between the United States and Mexico is obtained, the domestic fishery must be managed on a unilateral basis. This requires that the reduction fishery quota applied to the domestic fishery be appropriately specified to account for the Mexican catch. The U.S. quota might, for instance, be set at 50 percent or 70 percent of the total catch allowed by the chosen quota formula.

The choice of harvest formula should take into consideration the probable effect that the alternative formulas will have on the fish stock, the annual harvests, the economic value of the harvest, and the expected instability of the fishery. Tables 8.3-2 and 8.3-3 summarize some pertinent characteristics of the fishery under each of six optional harvest formulas. Figure 8.3-2 illustrates each of the optional harvest formulas. All of the formulas are for the anchovy reduction fishery. Each harvest formula can be described in terms of a CUTOFF below which biomass the quota would be zero; a SLOPE, which is the fraction of the biomass in excess of the CUTOFF which is to be harvested; and in some cases a LIMIT which is the maximum value the quota can assume. Only Option #1 has a specific LIMIT. The economic analysis in Appendix VI, however, indicates that there is an economically determined maximum harvest, which is essentially the largest harvest which the industry is likely to develop the capacity to take, given the investment costs and the expected profits. These economic maximum harvesting capacities are listed in Tables 8.3-2 and 8.3-3 in the row labelled "assumed limits." The resource characteristics described for Options 2 through 6 are dependent upon the assumption of the maximum harvest capacities.

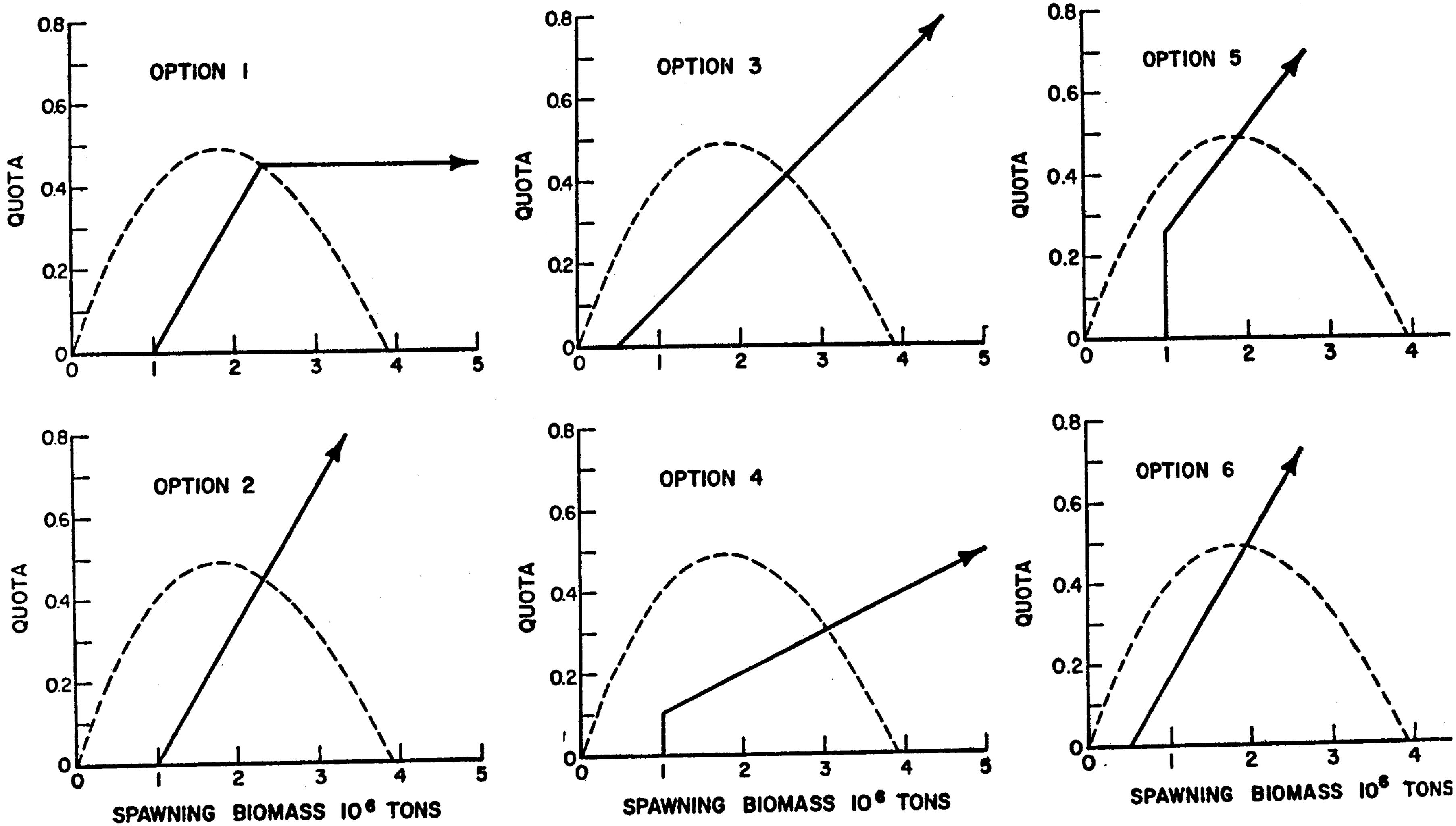

Figure 8.3-2. Optimal harvest quota formulas given in section 8.3.6 of the Anchovy Management Plan. Solid line represents quota as a function of biomass, dashed line represents estimated surplus production.

Table 8.3-2. Comparison of resource characteristics under various quota options. All biomass and harvests are in million short tons, assumes U.S. catch = 70%.

	Option 1	Option 2	Option 3	Option 4	Option 5	Option 6
Harvest Quota Formula Description						
CUTOFF	1.0	1.0	0.5	1.0	1.0	0.5
SLOPE (in percent of biomass excess of CUTOFF)*	33.0	33.0	20.0	10.0	25.0	33.3
LIMIT	0.45	none	none	none	none	none
Assumed Maximum <u>Total</u> Harvest Capacity	none	0.77	0.79	0.80	0.75	0.72
(See Appendix VI)	*For option 4 the quota is 0.1 at CUTOFF; for option 5, the quota is 0.25 at CUTOFF (see figure 8.3-2).					
Total Biomass Statistics						
Mean	2.87	2.55	2.57	3.00	2.17	2.16
Standard Deviation	2.22	2.01	2.06	2.23	1.91	1.92
Median	2.21	1.95	1.96	2.38	1.57	1.54
Percent of Years Biomass Will Fall Below 0.5	3.4	4.2	5.0	3.0	8.2	9.1
1.0	16.1	19.1	20.5	14.0	29.4	30.7
2.0	45.0	51.0	50.7	40.9	61.4	61.7
Total Catch Statistics						
Mean	0.290	0.371	0.355	0.284	0.384	0.378
Standard Deviation	0.181	0.302	0.266	0.210	0.287	0.269
Median	0.403	0.318	0.292	0.238	0.392	0.346
Percent of Years No Fishery	16.1	19.1	5.0	14.0	29.4	9.1
On Slope	37.9	56.3	80.4	81.9	48.3	64.3
At Assumed Maximum	47.0	24.6	14.6	4.1	22.3	26.6
U.S. Economic Statistics (million dollars)						
U.S. Potential Value Net of Operating and Capital Cost with Limited Access	3.1	3.1 - 4.5	3.0 - 4.4	2.8 - 4.0	3.0 - 4.3	3.0- 4.3

Table 8.3-3. Comparison of resource characteristics under various quota options. All biomass and harvests are in million short tons, assumes U.S. catch = 50%.

	Option 1	2	3	4	5	6
Harvest Quota Formula Description						
CUTOFF	1.0	1.0	0.5	1.0	1.0	0.5
SLOPE (in percent of biomass excess of CUTOFF)*	33.3	33.3	20.0	10.0	25.0	33.3
LIMIT	0.45	none	none	none	none	none
Assumed Maximum <u>Total</u> Harvest Capacity	none	0.97	0.97	0.96	0.91	0.90
(See Appendix VI)	*For option 4 the quota is 0.1 at CUTOFF; for option 5, the quota is 0.25 at CUTOFF (see figure 8.3-2).					
Total Biomass Statistics						
Mean	2.87	2.45	2.53	2.99	2.09	2.04
Standard Deviation	2.22	1.93	2.02	2.22	1.83	1.82
Median	2.21	1.89	1.94	2.38	1.52	1.47
Percent of Years Biomass Will Fall Below 0.5	3.4	4.4	5.1	3.0	8.5	9.6
1.0	16.1	20.0	20.8	14.1	30.3	32.2
2.0	45.0	52.8	51.4	41.0	63.0	64.2
Total Catch Statistics						
Mean	0.291	0.396	0.370	0.287	0.403	0.401
Standard Deviation	0.181	0.357	0.300	0.218	0.326	0.320
Median	0.403	0.297	0.287	0.238	0.376	0.323
Percent of Years No Fishery	16.1	20.0	5.1	14.1	30.3	9.6
On Slope	36.9	63.2	85.9	83.3	55.2	72.5
At Assumed Maximum	47.0	16.8	9.0	2.6	14.5	17.9
U.S. Economic Statistics (million dollars)						
U.S. Potential Value Net of Operating and Capital Cost with Limited Access	2.5	2.4 - 3.7	2.4 - 3.5	2.1 - 3.0	2.4 - 3.5	2.3 - 3.4

The characteristics which are probably of most interest are:

1. the median biomass occurring under each harvest formula,

2. the net economic value of the fishery under each harvest formula, and

3. the percent of years in which it is expected that the anchovy biomass will fall below the CUTOFF and, as a result, the reduction fishery will not be allowed to operate.

These three characteristics correspond roughly to some important objectives of fishery management, namely, conservation of the fish population, maximum economic utilization of the resource, and stability of the fishing industry. The annual biomass estimates are expected to be above the median biomass 50 percent of the time and below the median biomass 50 percent of the time. The economic value is a reflection of the overall contribution that the fishery makes to the economy. The percent of years in which the biomass falls below the CUTOFF equals the percent of years in which the anchovy reduction fishery will probably be shut down.

Option 1: (California Plan) Quota is 1/3 (33.3%) of the spawning biomass in excess of 1 million tons, with an upper quota limit of 450,000 tons.

Option 2: Quota is 1/3 (33.3%) of the spawning biomass in excess of 1 million tons.

Option 3: Quota is 1/5 (20%) of the spawning biomass in excess of 0.5 million tons.

Option 4: Quota is 1/10 (10%) of the spawning biomass, but is zero if the spawning biomass is less than 1 million tons.

Option 5: Quota is 1/4 (25%) of the spawning biomass, but is zero when the spawning biomass is less than 1 million tons.

Option 6: Quota is 1/3 (33.3%) of the spawning biomass in excess of 0.5 million tons.

Anticipated results of each optional harvest formula are summarized in Tables 8.3-2 and 8.3-3. The first reflects the assumption that the United States fishery will take 70 percent of the total harvest quotas. The second table reflects a 50 percent U.S. share of the catch. The biomass and catch statistics are similar in the two situations. The differences that do show up between the 50 percent and 70 percent U.S. shares are attributable to the different "assumed maximum harvest capacities." For more detailed explanation of this, see Appendix VI.

The first and fourth options maintain the highest levels of median biomass, while yielding the smallest average catches. Options three and six have relatively high average catches and will result in fishery shut-downs in the fewest number of years. The highest average catch among the options considered occurs with option five. Option five, however, yields the highest probability of fishery shut-down. Option two provides almost as much average annual yield as options five and six, and also is expected to maintain a reasonably large biomass of anchovies.

Discussion

The characteristics of each alternative harvest policy described above do not lead to any obvious conclusion as to what is optimal. This is because there are several unquantified objectives which are not given relative values. Any one of the proposed harvest policies could achieve the management objectives outlined in Section 8.1. Whether or not one of these policies is the "best" or whether there is any "best" policy is essentially a matter of judgement which, according to the Fishery Conservation and Management Act of 1976, is to be exercised by the Council.

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APPENDICES

APPENDIX I

REVIEW OF ANCHOVY BIOMASS ESTIMATION

Introduction

Three methods have been proposed for estimating the spawning biomass of northern anchovies from spawning products: Murphy (1966), Ahlstrom (1968), Smith (1972). This review discusses the procedure for estimating anchovy spawner biomass. This estimate is built from two components: 1) an estimate of anchovy larva abundance, 2) an estimation procedure that uses the relationship between anchovy larva abundance and historical information on sardine biomass and sardine larva abundance. These two topics are discussed respectively so that the reader gains an understanding of how the biomass estimates used in the anchovy management plan are calculated. A discussion of the more important assumptions used in estimation and their possible effect is reserved until last.

Why Larvae

Since the number of anchovies in the central stock cannot be directly enumerated, the stock must be sampled in order to determine biomass. Anchovy pass through three distinct life stages: eggs, larvae and fish (juvenile and adult). Biomass could be estimated from any of these stages. Presently, larvae are used. The reasons for this follow:

1) Schools of fish tend to be clumped: eggs, resulting from spawning schools, are also clumped. This results in a sample of high variance which in turn results in a highly variable biomass estimate. Because of diffusion and dispersion, larvae are more evenly distributed over the sample area and consequently yield a less variable estimate.
2) Eggs and larvae are sampled by plankton nets. Juveniles and adults are sampled by midwater trawls. Adults and juveniles avoid nets. Although there is some net avoidance in the advanced larval stages, it is minimal in comparison (P.Smith, NMFS, pers.comm.,April 1977).
3) Net retention is greater for larvae than for eggs (Smith, pers. comm., 4-18-77). Retention of eggs is highly variable with season, sometimes dropping to 10% retention. Net retention of larvae has been scientifically investigated (Lenarz 1972).
4) Egg life span, approximately 3 days, is less than that of larvae, approximately 30 days. Surveys of greater intensity and more precise timing would be required to sample eggs as effectively as larvae.

Larva Abundance Estimation

Sampling for anchovy larvae grew out of a sampling plan to determine the major spawning areas of the Pacific sardine. Originally, the sampling area extended from the Columbia River to Sebastian Vizcaino Bay in Baja California. The pattern of sampling stations was designed originally on the basis of a centric-systematic-area sampling design (Milne 1959). The same basic design remains in use today. However, as the spawning area was delimited the survey became concentrated off central California and Baja California. The sampling area was arbitrarily divided into regions. At present, there are 530 stations in 23 regions (Figure 1). The 23 regions cover 532,000 mi^2 (Table 1). The central anchovy stock is defined by 8 regions, indicated by *'s in Figure 1. The area of the central stock is 166,277 mi^2.

A detailed description of the equipment used and the processing of samples is contained in the NOAA Technical Report, NMFS CIRC-370, Collecting and Processing Data on Fish Eggs and Larvae in the California Current Region (Kramer, et al. 1972). In brief, stations are selected before each cruise. Standard plankton hauls are made at each selected station. If a station cannot be sampled because of equipment breakdown, weather or any other unforeseen circumstances, a nearby alternate may be chosen or the station omitted entirely. Stations are sampled on arrival whether day or night. Samples from each tow are preserved and taken back to the National Marine Fisheries Service in La Jolla for identification and counting.

The Regional Census Estimate

The number of larvae for each region are estimated from the following formula (Smith 1972, p. 856):

$$C_{k4} = 10\ A_r\ M^{-1} \left[\sum_{L=1}^{m} \left(a_i^{-1}\ b_i^{-1}\ c_i d_i \right) \right|$$

where C_{k4} = estimate of larva abundance in region r for each quarter of the year

A_r = area of region r in numbers of 10 m^2 areas of sea surface

m = number of stations sampled

a_i = area of mouth of the net

b_i = length of tow in meters

c_i = number of larvae in i^{th} sample

d_i = depth of tow

The part of the formula appearing inside the parentheses makes all tows comparable by adjusting the larval counts to a uniform equivalent of the amount of water strained per meter of depth fished. The regional census estimate is the average density per station times the size of the region. The estimate for each region is then summed to yield a quarterly estimate and the quarterly estimates are summed to produce the yearly larva abundance estimate.

Until 1966, cruises were made on a yearly basis. From 1966 to the present, complete cruises were made every 3 years, these being termed CalCOFI (California Cooperative Fisheries Investigation) years.

Table 2 lists the estimate of larva abundance X 10^9 for each quarter along with the yearly total for the central stock only. Although spawning occurs throughout the year, maximum spawning appears to occur during the winter and spring. Partial surveys, when all regions were not sampled, are indicated. No correction is made for these non-sampled regions and therefore larva abundance may be underestimated for these years. The estimates in Table 2 include the corrections from the recent review and edit of the CalCOFI egg and larva data which resulted in many minor and a few major changes in larva estimates given in past reports.

Figure 2 shows isopleths representing the average number of larvae per 10 m^2 expressed as 2^x for the years 1951-69. The 2.5 mm larvae are on the order of 5 days old and probably have not drifted far since spawning. The higher values which occur near shore represent more intense spawning than the lower values off shore. However, it can be seen that anchovy larvae occur in samples throughout the range of the central stock.

The distribution and abundance of anchovy larvae for the years 1954 and 1962 are shown in Figure 3. The estimated spawner biomass is 755 thousand tons for 1954 and 2,986 thousand tons for 1962. It can be seen that as the biomass increased by a factor of four, the geographic range of the larvae increased, as would be expected if the samples came from the entire stock. Figure 3 demonstrates that samples used to estimate anchovy spawner biomass come from an area representing the central stock. Thus, even though the total number of larvae sampled is small in comparison to the magnitude of the larvae produced, it is representative of the central stock.

Estimation of Anchovy Spawning Stock Biomass

There have been three methods developed for estimating anchovy spawning stock biomass: Murphy (1966), Ahlstrom (1968) and Smith (1972). Smith's method is the one presently used and following a brief discussion of the Murphy and Ahlstrom methods, it will be the topic of this section.

For the years 1951-1959, Murphy estimates the anchovy spawner biomass by multiplying the ratio of anchovy larvae to sardine larvae times an estimate of the sardine biomass. The sardine biomass is estimated from fisheries data. The ratio of larvae are corrected for differences in fecundity and net retention between the two species. Murphy estimates the net retention of sardine larvae to be about twice that for anchovy larvae. This ratio was later shown to be an overestimate (Lenarz 1972), the ratio being closer to 1:1 and consequently Murphy's estimates (Col. 1, Table 3) are considered to be high.

Ahlstrom's estimates are based on an estimate of the sardine stock size for 1958. With a knowledge of the total sardine catch and an estimate of fishing mortality, Ahlstrom is able to estimate the total sardine biomass for 1958. After correcting for fecundity and spawning frequency, the anchovy stock size is calculated by multiplying the sardine stock size times the ratio of anchovy larvae to sardine larvae. Anchovy stock sizes for other years can be calculated by multiplying the 1958 anchovy stock size times the quotient of anchovy larva abundance of the year to be estimated, divided by the larva abundance estimate for 1958. For 1958 and 1966, Ahlstrom estimates the anchovy biomass to range from 1,800,000 → 2,250,000 tons and 4,500,000 → 5,625,000 tons, respectively.

Smith's method differs from Murphy's method of using an anchovy to sardine larva ratio for each estimate, and from Ahlstrom's method of tying each abundance estimate to the 1958 sardine biomass estimate. Smith uses a series of regression and ratio estimates to establish a relationship between anchovy larvae and anchovy biomass. This relationship depends on the Murphy estimate of sardine biomass and anchovy and sardine larval abundance estimates for the years 1951-59, 1953 and 1959 excluded. Smith uses larva abundance estimates from the total CalCOFI area. The regions were different from those in present use (see Smith 1972, p. 854) and only 183 standard stations were included.

Smith's estimate is developed in three stages:

1) A regression estimate of the relationship between sardine larva abundance, Ls, and Murphy's (1966) estimates of sardine biomass, Bs. Assuming a zero intercept

$$Bs = .206\ Ls \qquad (1)$$

2) A ratio estimate of anchovy spawner biomass, Ba, is derived from the ratio of the estimates of anchovy larvae, La, to sardine larvae and Murphy's sardine biomass estimates.

$$Ba = c\left(\frac{La}{Ls}\ Bs\right) \qquad (2)$$

where c is a constant relating relative fecundity of sardines to that of anchovies, assumed to be .5.

3) The ratio estimate Ba is then regressed against the anchovy larva abundance. Again, assuming a zero intercept

$$Ba = .098\ La \qquad (3)$$

Equation 3 is used to calculate anchovy spawner biomass. It is used to calculate the biomass for the entire stock, and for the central stock. Table 4 lists:

1) Murphy's estimate
2) Smith's (1972) estimate for the total population within the CalCOFI area. This is calculated by multiplying the anchovy larva abundance as derived from the 183 standard stations times .098.
3) An estimate for the total population based on the current region design where all stations are included in the anchovy larva estimate, rather than 183 standard stations.
4) An estimate of the central stock, all stations included. This is obtained by multiplying .098 times the totals column of Table 2, the abundance of anchovy larvae for the central stock.

The central stock estimate, used in the PFMC Anchovy Management Plan, was calculated from recently edited time series of regional census estimates of anchovy larvae (Table 2) and as a result are different than those in the State of California anchovy management plan.

Assumptions

Various assumptions have been used in estimating spawning stock biomass. Assumptions used in estimating larval abundance and in estimating anchovy spawner biomass are discussed respectively. Only the major assumptions are included. In the entire estimation process, there are other assumptions besides these, but they have not been included because they are thought to be of relatively minor importance.

Estimating Larva Abundance

Sampling

In most sampling surveys there are complexities which reduce the precision and accuracy of the estimator. The regional census estimate may be limited in precision and accuracy because surveys are multipurpose, the sampling area is large and larva abundance is seasonal in intensity. The degree to which this exists is unknown.

Two major factors that reduce accuracy are:

1) Regions not sampled during a quarter contribute nothing to the biomass estimate: an underestimate results. Since those regions which are not sampled usually contribute little to the biomass estimate, the degree of underestimate is not great.

2) Within a region, the nearshore stations are usually sampled more intensely than the farshore. This could result in either an overestimate or an underestimate depending on the distribution of the larvae in the region. If the degree to which this happens has remained somewhat the same over the years, there may be little error introduced since the ratio of anchovy larvae to sardine larvae probably remains nearly the same under these conditions.

Two main factors that reduce precision are:

1) The number of samples within a region is often small. This naturally reduces the precision of the abundance estimate. Little can be done to avoid this. Combining regions may increase precision, but probably not greatly. Hopefully, future surveys can be designed to allocate samples to regions more appropriately.

2) Spawning intensity is seasonal. Thus during a quarter, larva abundance is continuously changing. Samples taken from a limited time frame within a quarter probably do not adequately represent all possible samples within that quarter. This may have occurred

during the years 1961-65 when there was only one survey per quarter. For earlier and later years, surveys were run monthly, often with two vessels, and the samples are most likely representative.

Temperature

Temperatures control growth rates. During cold years, the larvae grow slower and are more susceptible to sampling and an overestimate results. The converse is true of warmer than average years. Temperature corrections are in the process of being made.

It should be noted that temperature dependent growth rates are reliant on food supply. A larva living in warm water will have a higher growth rate only if there is an adequate food supply. Larvae would also likely have higher mortality rates from starvation due to higher metabolism. Complete temperature corrections can be made only with corrections for food supply. This later correction is formidable and immediate results are not expected.

Net Avoidance and Retention

As mentioned previously, larvae are targeted for sampling because they avoid the net less than juveniles and adults and are retained more than eggs. However, the larval stage represents the most dynamic period of growth in the life cycle and the validity of these assumptions depends on the age of the larvae.

Young larvae are small and have much less retention during the first few days of growth than during the ensuing stages. Corrections can be made but because the initial size of the larvae depends on the season, such corrections should take a more refined analysis than has been used so far.

The larger larvae with more developed nervous systems tend to avoid the nets. Investigations (Smith 1977, pers. comm.) show that avoidance increases with size. Dramatic differences exist between day and night size-dependent avoidance. Corrections are being developed.

If, over the years, avoidance and retention have remained the same, then the biomass estimates relative to the average value of the time series, would be accurate so that trends in the relative magnitude of the biomass would be valid.

In Smith's (1972) model, it is assumed that net retention is the same for both anchovy and sardine larvae. Based on Lenarz' (1972) work, this would give about a 10% underestimate of anchovy larvae abundance.

Prior to 1969, a .55-mm mesh width silk net was used. From 1969 to the present, a .505-mm mesh width nylon net has been used. Apparently, all anchovy larvae are retained by the new net (Lenarz 1972). The regional census estimates for these later years are adjusted to make them comparable with the old net. Net retention of larvae is an ongoing topic of research.

Assumptions in Spawner Biomass Estimation

Sardine Spawner Biomass

Biomass estimation depends on Murphy's (1966) estimates of sardine spawner biomass. Smith (1972) notes that any change in these estimates would bring about subsequent changes in the anchovy spawner biomass estimates. Murphy offered his analysis as a tentative solution and noted that with more information a re-examination would be appropriate. To this purpose, Mr. Alec MacCall is preparing a manuscript for publication.

MacCall's analysis includes 5 more years of landings data, 1961-65. MacCall also makes important changes in mortality estimates and maturity at age. Murphy chose natural mortality, fishing mortality and maturity at age to agree with egg counts from CalCOFI surveys. Since we are now using Murphy's estimates to calibrate larva surveys, the process is circular. It is pointed out that the resulting agreement between Murphy's biomass estimates and spawning products is more precise than should be expected.

MacCall also points out that Murphy included sardine landings from the southern stocks in his analysis. This would tend to make the accepted estimates of sardine biomass too large. With the removal of the portion of the catch from the southern stock, MacCall's analysis yields substantially lower estimates. When the area of the larvae survey is also restricted to that of the central stock, the larva census estimate is again decreased. On preliminary examination, the constant in equation 1 is relatively unaffected.

Multiple Spawning

Northern anchovy and Pacific sardine most likely spawn more than once during a season. Estimates for Pacific sardine range from 1½ to 3 times per year but are inconclusive (MacGregor 1957; Ahlstrom 1960). Smith (pers.comm., April 1977) concluded from multiple peaks in the occurrence of eggs and larvae within a spawning season that anchovies apparently spawn with a frequency of 1 to 2 times per year. For simplicity, equality of spawning frequency between the species is now assumed even though the spawning frequency of sardines is most likely equal to or greater than the frequency for anchovies. This assumption likely results in an underestimate of the anchovy biomass. Research on spawning frequency of the northern anchovy is now being planned for the coming year.

Fecundity

The estimated number of eggs spawned per gram of female in one batch for the Pacific sardine and northern anchovy are 263 (MacGregor 1954) and 574 (MacGregor 1968), respectively. Hence the fecundity of sardines to anchovies is approximately 0.5. Although these figures are 23 and 9 years old, respectively, they are probably still valid. Recently, Knaggs (MS) reported the estimate for a second sample of anchovies to be 556 eggs/gram. This probably does not represent a significant deviation from the previous estimate. The estimate of relative fecundity of sardines to anchovies is .46 to .47 and the estimate of 0.5 used in equation 2 yields a maximum 8% over-estimate of anchovy spawner biomass.

Natural Mortality

It is assumed that natural mortalities incurred by sardines and anchovies during the egg and larval stages are the same. It is further assumed that this relationship has been consistent since 1951. P. Smith (NMFS, pers. comm., April 1977) has done research that indicates anchovy embryonic mortality is the greater of the two. This would make the present anchovy spawner biomass estimate an underestimate. Research on variation in egg and larva mortality is in progress.

Conclusions

The anchovy spawner biomass estimate is built on information from several different sources. Consequently, the precision and accuracy of these primary sources is reflected in the biomass estimate. Lack of precision in the estimate may come from more than one source and it is difficult to judge the absolute level of precision without detailed analysis. However, imprecision does not result in an erroneous estimate but in one of variability. Thus, due to imprecision we would expect the present estimate to be centered, but somewhat more scattered than desirable, about the true population biomass. Imprecision of the present estimate does not affect the observed trend in abundance for the past 25 years.

Lack of accuracy can bring about an overestimate or an underestimate. Both of these deviations have occurred, and it is difficult to judge exactly the effect of their mix. However, it is reasonable to assume that the estimator bias is downward and that the estimates used in the Anchovy Management Plan are conservative. This conclusion is reached because: 1) wherever possible, an intentional downward bias has been introduced; 2) influences of upward bias are, at first approximation, minimal in comparison.

Refinements in the spawning biomass estimates of the central stock of northern anchovy are forthcoming. Increased sophistication of these new analyses will improve the estimates of spawning biomass and will provide estimates of their variance. The extent of the absolute differences between forthcoming estimates of spawning biomass and the current estimates in use are unknown. However, the increasing trend in biomass and the relative differences between the annual estimates will likely remain unchanged from those of the current estimates.

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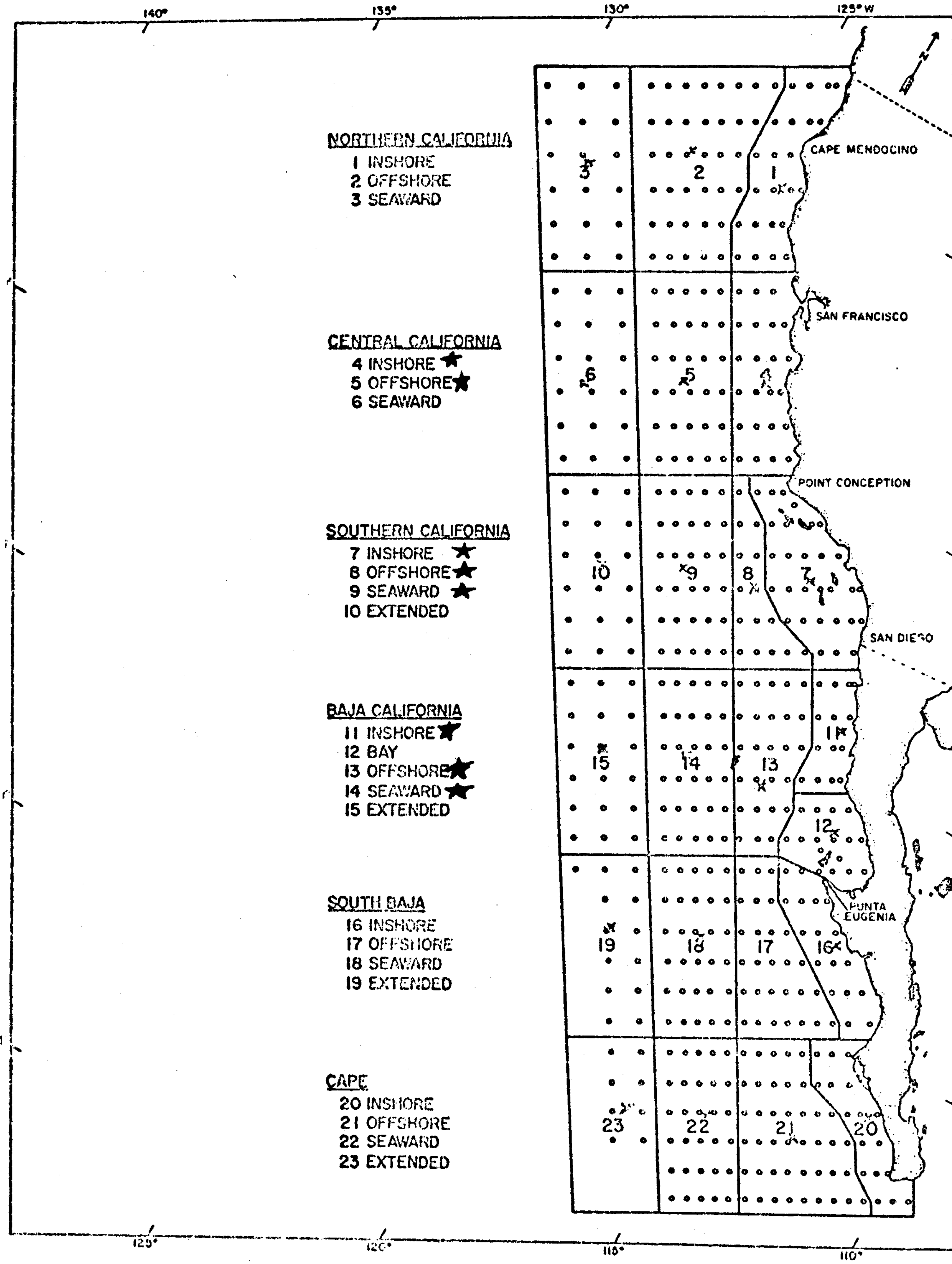
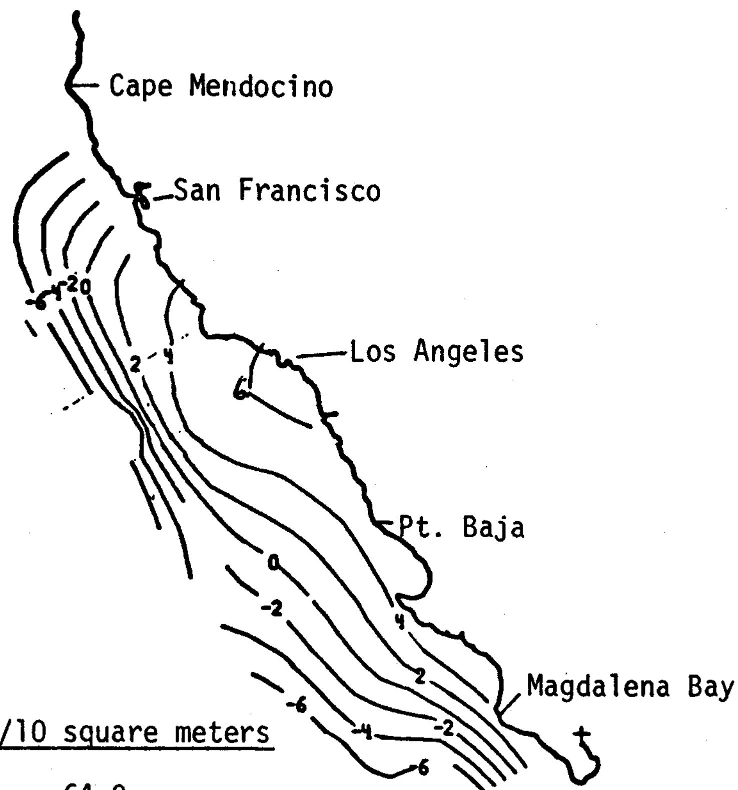


Figure 1. Regions of CalCOFI area with sampling stations. Regions of the central stock are followed by stars (from Duke 1976).



Code	Larvae/10 square meters
6	64.0
4	16.0
2	4.0
0	1.0
-2	0.25
-4	0.06
-6	0.016

Figure 2. Isopleths representing the average number of larvae per 10 m^2 per quarter as expressed by 2^X for all anchovy larva data taken between 1951 and 1969 (Smith, pers. comm., April 1977).

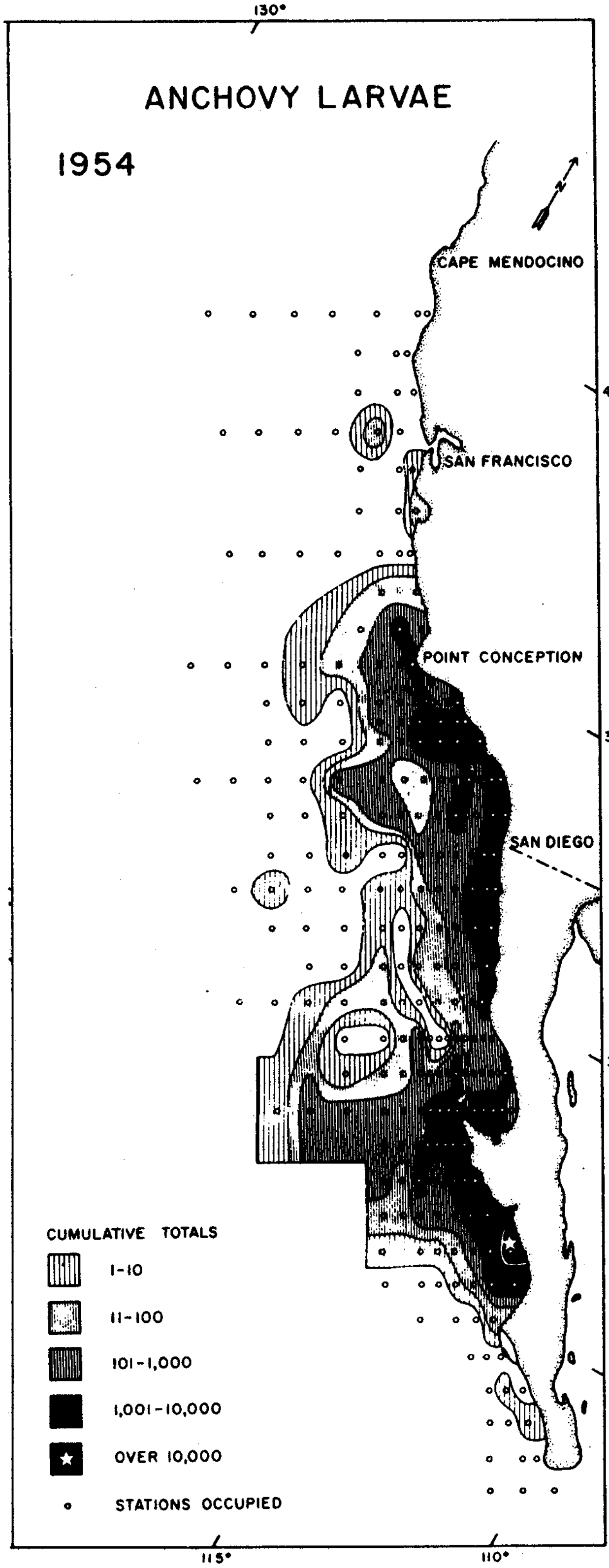


Figure 3. Distribution and abundance of anchovy larvae for the years 1954 and 1962 (Ahlstrom 1966). The anchovy abundance estimates for these years are 1645 x 10^3 and 5890 x 10^3 tons, respectively (from Table 3).

24 CALCOFI POOLING REGIONS

Name	Abbrev.	Area mi^2	Number of 10 m^2 areas
1. Northern California Inshore	(NCI)	16,352	5.608579021×10^9
2. Northern California Offshore	(NCO)	34,400	1.179886976
3. Northern California Seaward	(NCS)	28,800	9.878123520
4. Central California Inshore	(CCI)	17,799	6.104886130
5. Central California Offshore	(CCO)	28,800	9.878123520
6. Central California Seaward	(CCS)	28,800	9.878123520
7. Southern California Inshore	(SCI)	20,106	6.896164982
8. Southern California Offshore	(SCO)	12,000	4.115884800
9. Southern California Seaward	(SCS)	28,800	9.878123520
10. Southern California Extended	(SCE)	28,800	9.878123520
11. Baja California Inshore	(BCI)	9,244	3.170603258
12. Sebastian Viścano Bay	(SVB)	10,622	3.643244029
13. Baja California Offshore	(BCO)	20,764	7.121852666
14. Baja California Seaward	(BCS)	28,764	9.865775866
15. Baja California Extended	(BCE)	28,800	9.878123520
16. Southern Baja Inshore	(SBI)	14,253	4.888642171
17. Southern Baja Offshore	(SBO)	22,400	7.682984960
18. Southern Baja Seaward	(SBS)	28,800	9.878123520
19. Southern Baja Extended	(SBE)	28,800	9.878123520
20. Cape Inshore	(CI)	14,512	4.977476685
21. Cape Offshore	(CO)	33,600	$1.152447744 \times 10^{10}$
22. Cape Seaward	(CS)	28,800	9.878123520×10^9
23. Cape Extended	(CE)	28,800	9.878123520
24. North Central Pacific	(NCP)	> *	> > >

Table 1. Regions of the CalCOFI survey area. Region 24 has no set boundaries; it contains all CalCOFI stations not in the other 23 regions (see Figure 1) (from Duke 1976).

Estimated number of larvae x 10^9 for central stock					
Year	Winter	Spring	Summer	Fall	Total
1951	298*	690	224	629	1,841
52	407*	457	386	350	1,600
53	1,210*	373	641	2,984*	5,208
54	4,469	988	1,629	752*	7,838
55	5,588*	1,709*	1,228*	93*	8,618
56	1,911*	1,206	1,611*	216*	4,944
57	5,954	4,308*	1,199*	499*	11,960
58	8,114*	5,236	1,639*	98*	15,087
59	6,341*	8,155	857*	87*	15,440
60	7,552	7,547	578*	36*	15,713
61	992	6,714	4,025	96	11,827
62	4,814	23,567	1,856*	241	30,478
63	17,377	24,818	829*	383*	43,407
64	8,941	14,383	5,523	752*	29,599
65	19,155	22,690	5,695	- **	47,540***
66	15,103	15,865*	4,140	1,344*	36,452
69	19,756	6,538*	2,707*	1,593	30,594
72	8,213	14,335	3,361	2,464	28,373
75	29,754	4,071	1,460	1,482	36,768

Table 2. Larva abundance estimates x 10^9 by quarters for the central stock (from Smith, pers. comm. 1977). Estimates for 1969, 1972 and 1975 have been adjusted for a new plankton net.

* partial surveys

** no estimate is available for 1965

*** estimate is based on 3 quarters only

ANCHOVY SPAWNER BIOMASS IN 10^3 TONS

Year	Total Stock			Central stock
	Murphy's estimate	Smith (1972)	Revised Estimate	
1951	1,539	637	526	180
52	1,440	797	590	156
53	4,892	1,335	1,042	510
54	4,142	1,816	1,645	768
55	4,208	1,676	1,436	846
56	2,549	1,491	1,468	485
57	3,159	1,964	1,425	1,172
58	5,058	2,771	2,029	1,479
59	7,372	2,299	1,951	1,514
60		3,079	3,123	1,540
61		3,189	3,141	1,159
62		6,248	5,890	2,986
63		6,030	8,078	4,254
64		5,121	3,604	2,901
65		7,771	6,996	4,659
66		5,116	4,128	3,572
69				2,999
72			4,923	2,784
75				3,603

Table 3. Anchovy spawner biomass estimates from 1) Murphy's estimate, 2) Smith (1972) using 183 standard stations, 3) revised estimates using all stations and new regional strata and 4) central stock estimate.

APPENDIX II

ANCHOVY POPULATION GROWTH MODEL DESCRIPTION

Introduction

The following growth model was designed to provide information for evaluating various management alternatives. Since there has never been a continuous significant fishery on the resource such that the fishery dynamics could be elaborated directly, we have used an indirect approach. CalCOFI surveys, which have been undertaken since 1951, have provided us with a remarkable time series of population size data from which some of the natural growth characteristics could be inferred. Since population growth represents potential equilibrium yield, we have employed standard fishery equations to project the growth model to a fishery model. While not having the concrete basis of fishery experience, the model may actually avoid much of the danger inherent in standard fishery models which require often questionable fishery information such as catch per unit effort. A stochastic form of the model was developed to evaluate the effects of natural variability in the resource and in our observations of its size.

Population Processes

Spawning biomass is defined as the total weight of anchovies in the population which have spawned at least once in their lives. The abundance of anchovy larvae in the populated area will be assumed to be proportional to the spawning biomass at some time when all fish capable of spawning are actually doing so. Since spawning usually reaches peak intensity in the spring, but can occur throughout the year, the annual census will be assumed to measure the spawning population on March 1 of each year. Future studies of seasonal spawning intensity may allow this assumption to be more closely met by using only winter or spring quarter egg and larva surveys.

The actual variation of spawning biomass throughout the year may look like the sinusoidal curve in Figure 1A. At "A", recruitment and somatic growth rates exceed mortality rate so the population rapidly increases as new spawners enter the pool. At "B", the combined rates equal zero and the spawning population reaches peak biomass for the year. At "C", the recruitment rate has become very low so that mortality is the dominant force, causing the spawning biomass to fall until the next season's recruitment begins to enter the population. At "D", a fall spawning is described, which would appear as a ripple in the main population cycle.

To be useful, a population model must simplify the events described above and relate them to quantities which we can measure. The model proposed here assumes that recruitment can be described as entering the spawning biomass en masse on March 1 of each year (Figure 1B). The ichthyoplankton survey gives a spawning biomass estimate which is shown at "E." Subsequently, the cohort consisting of all spawners included in "E" decline in biomass due to natural and fishing mortality, which are partially offset by somatic growth. "F" shows the remaining biomass at the end of the year which is augmented by the next recruitment (R) to give a new spawning biomass cohort at "G." The mathematical relationships between the biomasses at points "E," "F" and "G" are now easily described by standard fishery equations.

The population at "F" is a function of the population at "E" and the combined rates of growth, fishing, and natural mortality. If the rate of growth is expressed in similar fashion to rates of mortality, the equations become very straightforward. Letting G be the instantaneous or specific rate of growth:

$$G = \frac{dW}{Wdt}$$

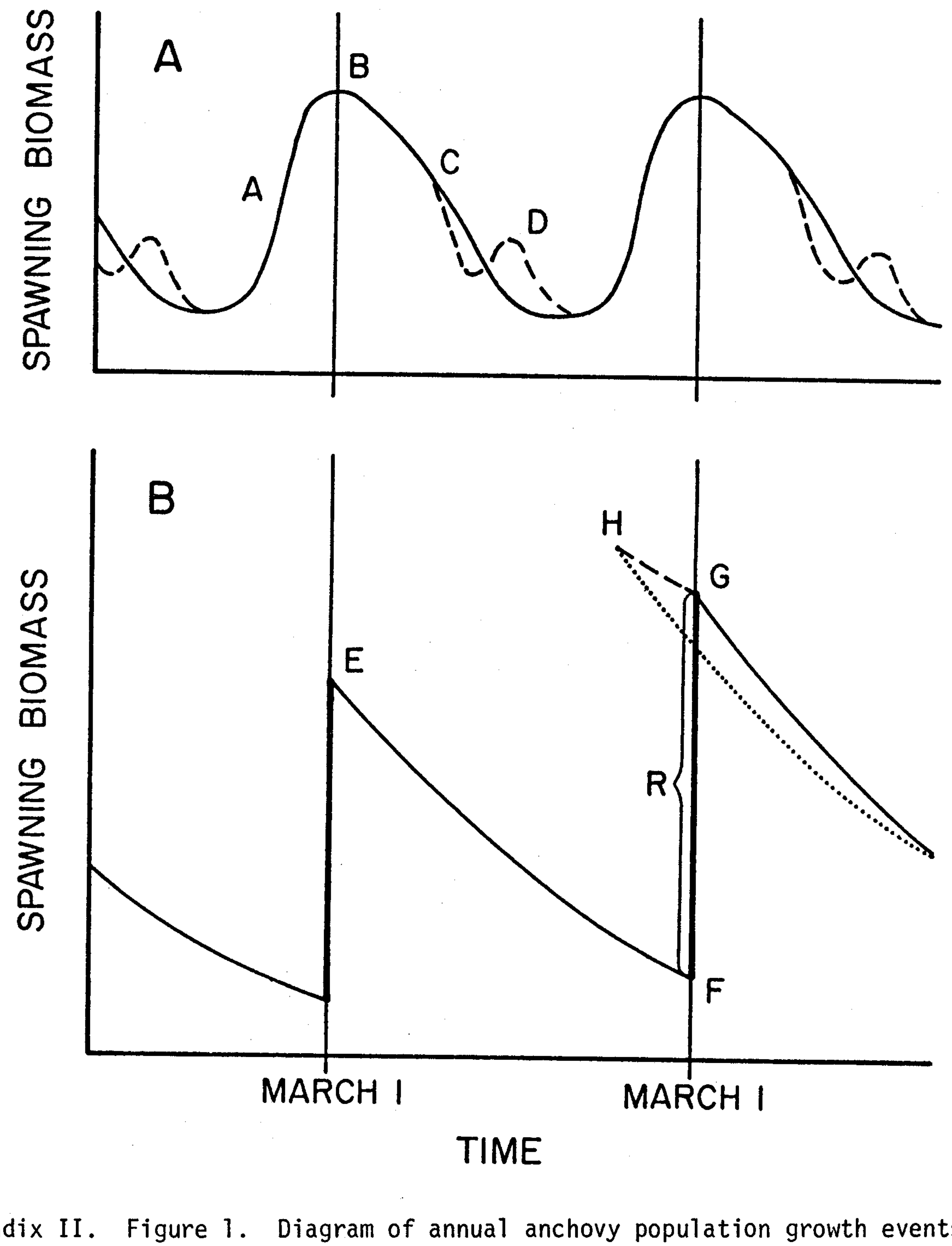
where W is fish weight, the combined instantaneous rate of loss of cohort biomass is F+M-G. The survival of biomass from March 1 (T) to time $T+\Delta t$ is given by

$$B_{T+\Delta t} = B_T e^{-(F+M-G)(\Delta t)} \qquad (1)$$

and the catch during the period is

$$C = B_T \; \frac{F}{F+M-G} \left(1-e^{-(F+M-G)(\Delta t)}\right) \qquad (2)$$

The biomass at "G" is the sum of the biomass at "F" and recruitment. Ideally, we could employ a model giving recruitment as a function of past biomasses, age compositions, physiological states, and environmental variables, all stratified by area and time, so that the actual processes determining recruitment are accounted for. However, such a model is an impossibility



Appendix II. Figure 1. Diagram of annual anchovy population growth events. Figure 1A represents true pattern of events; and Figure 1B is the model. See text for labelled events.

at present due to insufficient knowledge and insufficient data. Rather, an empirical recruitment model is sufficient for our present management efforts.

Logistic Growth

Having witnessed the growth of the anchovy population since 1951 under conditions of negligible fishing pressure (Figure 2), we can fit an empirical growth curve to the time series and obtain an expression for recruitment indirectly. The time series of anchovy spawning biomass shows an initial slow increase, followed by a sudden upsurge in the early 1960's, followed by fluctuations about what appears to be an equilibrium condition. A convenient empirical description of this trend is that given by the logistic population growth equation (Pielou 1969).

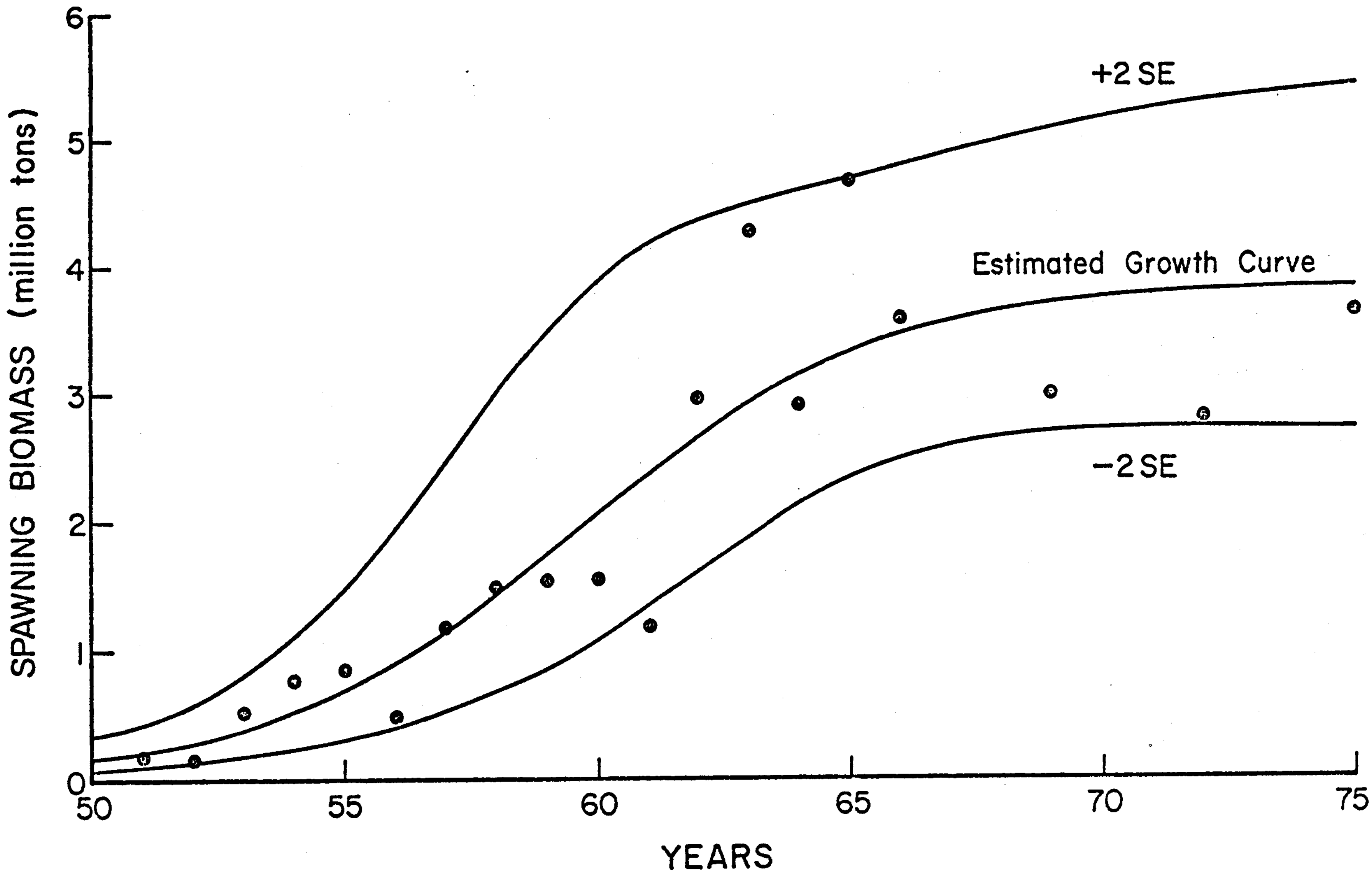
$$B_t = \frac{B\infty}{1+e^{-rt+A}} \qquad (3)$$

where $B\infty$ is asymptotic biomass, r is intrinsic rate of increase, and A is a constant relating to conditions at time t=0. This model not only fits the observed points reasonably well (Figure 2), but also has several theoretical and practical advantages.

The logistic growth equation arises from a parabolic relationship between growth rate and population size:

$$\frac{dB}{dt} = Br\,\frac{B\infty - B}{B\infty} \qquad (4)$$

This equation has only two fitted parameters, $B\infty$ and r, both of which have direct interpretations. Alternative equations to (3) such as a polynomial function would require more fitted parameters which would have no such clear interpretation. If the population were altered in size by natural or artificial events (such as a fishery), the logistic equation provides a simple description of the subsequent population growth we could expect, based on previously observed trends. Extrapolations of population growth to future time periods are bounded by 0 and are asymptotic to $B\infty$ rather than unbounded as in the case of a polynomial. The differential equation (4) gives maximum population growth rate at one-half the maximum population size, which is probably the most reasonable assumption pending future evidence of skewness.



Appendix II. Figure 2. Historical increase in anchovy spawning biomass with fitted growth curve and confidence limits.

Basic Model

Since the ichthyoplankton surveys give population estimates at time intervals of 1 year, the annual difference equation corresponding to the logistic equation (3) is a useful description of biomass "G" as a function of biomass "E" in Figure 1B:

$$B^{*}_{T+1} = B_{T+1} + R_{T+1} = \left(\frac{1}{B_\infty} + \left(\frac{1}{B_T} - \frac{1}{B_\infty}\right) e^{-r}\right)^{-1} \qquad (5)$$

when no fishing occurs. B^{*}_{T+1} represents a new cohort formed from the surviving biomass of the old cohort B_{T+1} (given by equation 1) and recruitment R_{T+1}. Recruitment is therefore given by equation (5) less equation (1) for F=0:

$$R_{T+1} = \left(\frac{1}{B_\infty} + \left(\frac{1}{B_T} - \frac{1}{B_\infty}\right) e^{-r}\right)^{-1} - B_T e^{-(M-G)} \qquad (6)$$

Thus the only independent variable in this spawner-recruit relationship is the biomass 1 year prior to recruitment. In reality, the recruitment at time T+1 is provided by the previous year's spawning at time T, but also to some extent those at T-1 and possibly at T-2. Since the spawning biomasses at times T-1 and T-2 are relatively near that at time T, the error resulting from our simplification to a 1-year cycle should be small.

Extended Model

The basic anchovy population model does not allow the possibility of catching pre-spawners. Since pre-spawners are a small component of the catch, the model should reflect this fact.

Fish were assumed to become partially available to the fishery (with $\emptyset$ as the coefficient of relative availability) for a length of time τ before spawning on March 1 (time T). The quantity M-G is assumed to be the same as that for spawners. The quantity of fish alive at time $T-\tau$ would have been

$$R_{T+1-\tau} = R_{T+1} e^{(M-G)\tau} \qquad (7)$$

where R_{T+1} is as given in equation (5) and $R_{T+1-\tau}$ denotes equivalent recruitment at that time earlier than March 1 when pre-spawners first become available to the fishery ("H" in figure 1B). Since fishing begins at time $T+1-\tau$, the amount of fish remaining at time T+1 is

$$R^*_{T+1} = R_{T+1-\tau} e^{-(\phi F+M-G)\tau} = R_{T+1} e^{-\phi F\tau} \tag{8}$$

and the biomass at T+1 is

$$B^*_{T+1} = B_T e^{-(F+M-G)} + R_{T+1-\tau} e^{-(\phi F+M-G)\tau} \tag{9}$$

$$= B_T e^{-(F+M-G)} + R_{T+1} e^{-\phi F\tau} \tag{10}$$

The total catch of fish during the year is

$$C = B_T \frac{F}{F+M-G}\left(1-e^{-(F+M-G)}\right) + \omega R_{T+1} e^{(M-G)\tau} \frac{\phi F}{\phi F+M-G}\left(1-e^{-(\phi F+M-G)\tau}\right) \tag{11}$$

where ω is a coefficient of pre-spawner body weight in units of adult fish body weight.

Parameter Estimation

Basic Model

Two methods of estimating the logistic growth parameters were used. First, approximate values were estimated by fitting larva census estimates by equation (3) using a curvilinear least-squares regression procedure. This method requires us to ignore the effects that actual harvests may have had on the population growth time series, and therefore tends to bias the parameter estimates. An advantage of the method is that it gives approximate standard errors and covariance for the estimated parameters. The second estimation procedure was an iterative least-squares estimate using the growth model itself as the predictor. While providing better parameter estimates, standard errors could not be estimated. The parameter estimates given by the two methods are in Table 2.

First Method

The logistic equation (3) was fit to annual biomass estimates for the anchovy central stock using the curvilinear least-squares regression method (Marquardt algorithm) described in Conway, Glass and Wilcox (1970). Much of the error in larva survey estimates arises from the clumped distribution of the spawning products. Taft (1960) showed the negative binomial distribution applied to such survey samples, with the characteristic that the variance increases rapidly with increases in the mean (abundance). Zweifel and Smith (pers. comm.) give a preliminary estimate of CalCOFI larva survey sampling error based on the negative binomial distribution in which 95% confidence interval is described by a multiplicative factor of 1.2. Logarithmic transformation equalized the variance at high and low biomasses, supplying the condition of homoscedasticity necessary for proper regression estimates. Since use of log-transformed variables results in the regression being fit to the geometric mean of the raw data, a correction described by Beauchamp and Olson (1973) was applied to estimate the appropriate arithmetic mean. This correction consists of multiplying the antilog estimate of the dependent variable by $e^{(s^2/2)}$ where s^2 is the variance of the estimate (RSS/n-3). In terms of the logistic growth equation (3), the correction is applied to B_∞. The relevant parameter estimates are given in Tables 1 and 2.

Confidence limits for the growth curve (3) and for the corresponding growth rate curve (4) are obtained by the "delta method," which is basically a Taylor series approximation (Seber 1973). In Seber's notation, the approximate variance of a function g which has parameters x_i, (i=1,2,...,n) is given by

$$V[g(x_1,x_2,\ldots)] = \sum_{i=1}^{n} V[x_i] \left(\frac{\partial g}{\partial x_i}\right)^2 + 2 \sum_{ij} \operatorname{cov}[x_i,x_j] \left(\frac{\partial g}{\partial x_i}\right)\left(\frac{\partial g}{\partial x_j}\right) \qquad (12)$$

Since the log transform of equation (3) was used in the regression, function g is the logarithm of (3), and the partial derivatives must be calculated appropriately. Also, B_∞ and its covariances do not yet incorporate the geometric mean correction factor, which in this case must be applied after taking antilogs of the estimated confidence limits. The approximate variance from equation (12) is

$$V(\ln B) = V_{B_\infty} \left(\frac{\partial \ln B}{\partial_{B_\infty}}\right)^2 + V_r\left(\frac{\partial \ln B}{\partial r}\right)^2 + V_A \left(\frac{\partial \ln B}{\partial A}\right)^2$$

Table 1. Variance-covariance matrix for growth parameters estimated by curvilinear regression.

			B_∞					
			10^{15} larvae		10^3 tons		r	A
			GM	AM	GM	AM		
B_∞	(10^{15} larvae)	GM	$(6.513)^2$					
		AM		$(6.927)^2$				
	(10^3 tons)	GM			$(638.2)^2$			
		AM				$(678.9)^2$		
r			-221.6	-235.7	-21.71	-23.10	$(0.0560)^2$	
A			546.8	581.6	53.6	57.0	0.00677	$(0.271)^2$

n = 19 df = 19-3 t_0 = 1950

Table 2. Estimates of logistic growth parameters.

Parameter	Curvilinear regression (no catches)	Iterative solution (corrected for catches)
B_∞ (GM)	3.611×10^6 tons 36.85×10^{12} larvae	3.649×10^6 tons
B_∞ (AM)	3.841×10^6 tons 39.19×10^{12} larvae	3.888×10^6 tons
r	0.3369	0.3638
A	3.231	3.195
B(t=0) (GM)	137.3×10^3 tons 1.401×10^{12} larvae	143.6×10^3 tons
B(t=0) (AM)	146.0×10^3 tons 1.490×10^{12} larvae	153.1×10^3 tons
RSS	1.976	2.035
GM to AM correction factor	1.0637	1.0657

$$+ 2\mathrm{cov}\ (r,B_\infty) \left(\frac{\partial \ln B}{\partial B_\infty}\right) \left(\frac{\partial \ln B}{\partial r}\right) + 2\mathrm{cov}\ (r,A) \left(\frac{\partial \ln B}{\partial r}\right) \left(\frac{\partial \ln B}{\partial A}\right)$$

$$+ 2\ \mathrm{cov}\ (A,B_\infty)\left(\frac{\partial \ln B}{\partial B_\infty}\right) \left(\frac{\partial \ln B}{\partial A}\right) \qquad (13)$$

where the partial derivatives are

$$\frac{\partial \ln B}{\partial B_\infty} = \frac{1}{B_\infty}$$

$$\frac{\partial \ln B}{\partial r} = \frac{te^{-rt+A}}{1+e^{-rt+A}}$$

$$\frac{\partial \ln B}{\partial A} = \frac{e^{-rt+A}}{1+e^{-rt+A}}$$

The approximate 95% confidence limits were calculated by the regression estimates $\pm$ 2 standard errors (Figure 2).

Confidence limits for the growth rate equation (4) were also calculated by the delta method approximation. Letting B' signify annual population growth rate $\frac{dB}{dt}$, the variance estimated by equation (12) is

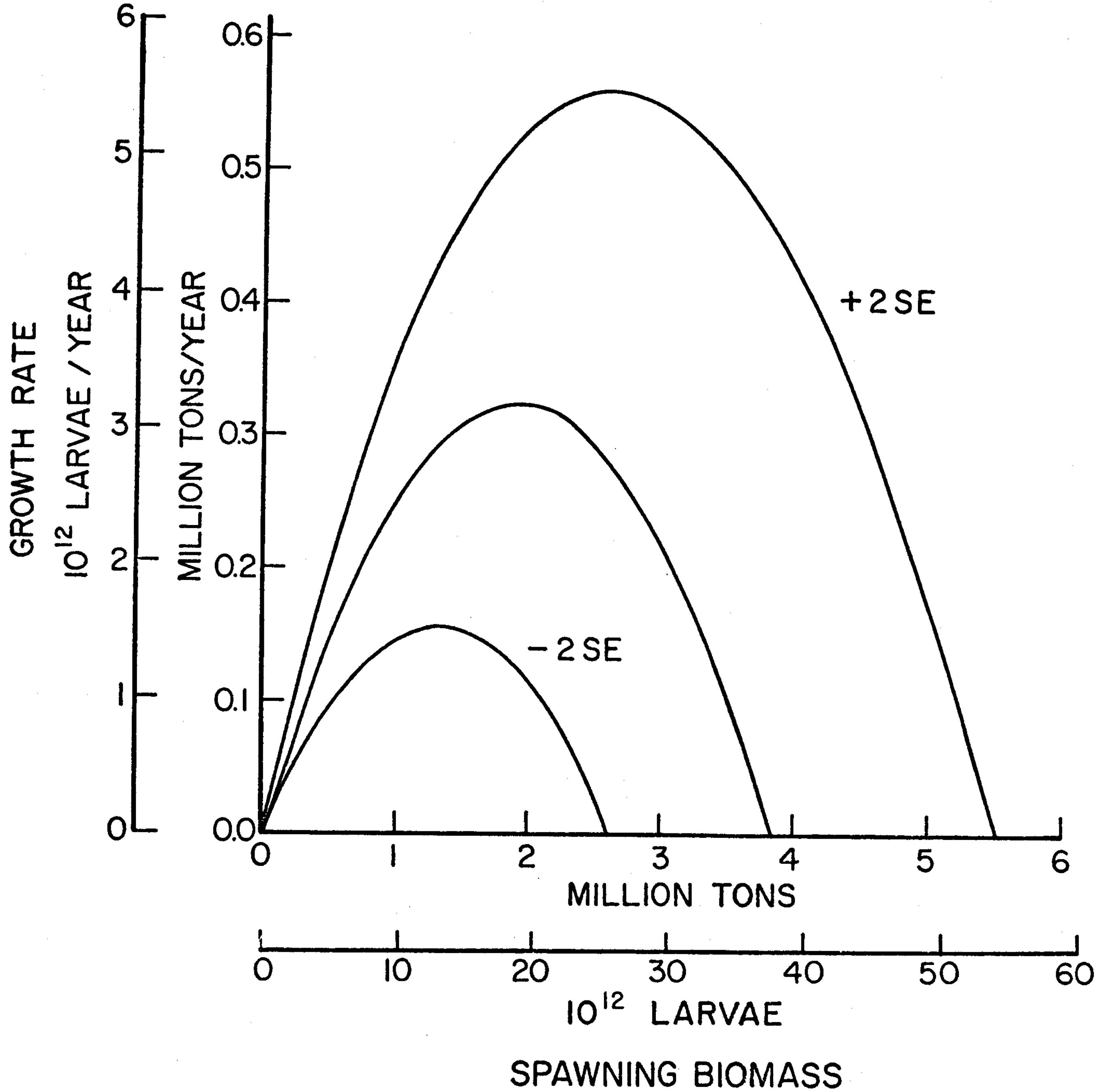
$$V(B') = V(r) \left(\frac{\partial B'}{\partial r}\right)^2 + V(B_\infty) \left(\frac{\partial B'}{\partial B_\infty}\right)^2 + 2\mathrm{cov}(r,B_\infty) \left(\frac{\partial B'}{\partial r}\right) \left(\frac{\partial B'}{\partial B_\infty}\right) \qquad (14)$$

where

$$\frac{\partial B'}{\partial r} = B-\frac{B^2}{B_\infty}$$

$$\frac{\partial B'}{\partial B_\infty} = \frac{rB^2}{B_\infty 2}$$

The parameter estimates used in this calculation were already corrected for geometric mean bias, and the approximate 95% confidence limits were calculated by the estimate ± 2 standard errors (Figure 3). The growth rate curve given by equation (4) is not exactly that which arises from the entire



Appendix II. Figure 3. Logistic growth rate curve and confidence limits, with biomass alternatively measured in tons or spawned larvae.

model since (4) describes growth in a continuous state, while the model is based on discrete annual events. In effect, the model (5) tends to reflect average growth rates over single-year growth segments of the curve given by (4). One result is that highest population growth rate occurs at an initial population size slightly smaller than $B_\infty/2$, such that the center of the segment is $B_\infty/2$. The population growth rate curve arising from the model is therefore slightly skewed rather than symmetrical as in a purely logistic model.

The above estimates of logistic growth parameters were made under the assumption that actual harvest of anchovies during the period had negligible effect on population growth. Such an assumption was necessary in order to obtain the parameter error estimates by the curvilinear regression procedure. The following parameter estimates for harvest-corrected growth incorporate a catch correction but do not have error estimates; the magnitude of error is very likely the same as those previously given.

Second Method

The second method employs the model itself to give predicted biomass values rather than the simple equation in the previous method. Since the model is rather complicated, an iterative procedure was used to obtain a least-squares estimate of the growth parameters. Standard errors of the individual parameters could not be obtained by this method.

In order to correct for the effect of harvests, a quantity was subtracted from the predicted population size such that it was equal to the net effect of the previous year's harvests. This quantity was determined by an application of cohort analysis. Equations (1) and (2) are analogues of the usual catch equations which employ only M and F. In this case, G is a constant instantaneous rate and can therefore be combined with F and M which are also constant instantaneous rates. Using the value of the specific growth rate constant developed in Appendix IV, the quantity (M-G) = 0.8 was substituted for M in the usual cohort analysis equations (Tomlinson 1970) enabling cohort analysis of a population measured in weight rather than numbers.

Monthly catches in weight were compiled for a March to February year. California landings by month were obtained from the California Marine Fish Landings Series of Fish Bulletins from the California Department of Fish and Game. Bait landings were also obtained from the above source, but only annual totals are given. The bait catch was divided equally between the months of June, July, August and September, the months of maximum bait harvest. Mexican catches were obtained from the Anchovy Plan, Table 3.2-4, and from MacCall, Stauffer and Troadec (1976, p. 6) for years not covered in the previous source. Since no data are available on Mexican catches before 1962, arbitrary values of 100 tons in 1956 increasing by 100 tons annually to 500 tons in 1960 were used. Again, only annual totals are available, so the Mexican catches were divided into the same 4-month period as the bait catch. This division is consistent with the Ensenada-based fishery, which operates mainly during the summer months.

A "forward solution" form of cohort analysis was used to find the surviving biomass of the spawners at the beginning of the next spawning. An initial value of fishing mortality was obtained by solving equation (2) for F given the total March landings and the larva survey estimate of spawning biomass (March 1). Monthly biomasses are then estimated sequentially to give biomass on the following March 1. This ending biomass was then subtracted from the biomass which would be indicated by equation (1) had there been no fishing. This difference is the catch correction factor applied to biomasses predicted by equation (5) and can be viewed as that catch which would have the same net effect as the true catches, but that would have been taken entirely on the last day of February. Catch correction data are given in Table 3.

Parameter values were estimated by a least-squares approximation method (Stauffer 1973): using log transformation as before, sums of squares of the deviations of observed from predicted values (i.e., residual sum of squares, RSS) were calculated for each of the 27 or more trial combinations of r, B_∞ and B(t=0) using at least three trial values of each parameter. A multiple linear regression program (BMDO2R) was utilized to estimate coefficients of the following equation used to model the residual sum of squares response surface:

$$RSS = b_0 + b_1 B_\infty + b_2 r + b_3 B(t=0) + b_4 B_\infty^2 + b_5 r^2$$
$$+ b_6 B(t=0)^2 + b_7 r B_\infty + b_8 B_\infty B(t=0) + b_9 r B(t=0) \qquad (15)$$

The values of r, B_∞ and B(t=0) that minimize the RSS are the solution to the three first order partial derivatives of (15) with respect to r, B_∞ and B(t=0), set equal to zero, i.e.,

$$\frac{\partial RSS}{\partial B_\infty} = b_1 + 2b_4 B_\infty + b_7 r + b_8 B(t=0) = 0$$

$$\frac{\partial RSS}{\partial r} = b_2 + 2b_5 r + b_7 B_\infty + b_9 r = 0$$

$$\frac{\partial RSS}{\partial B(t=0)} = b_3 + 2b_6 B(t=0) + b_8 B_\infty + b_9 r = 0$$

These can be rewritten in terms of matrix algebra as

$$Dx = d$$

where the matrix D = $\begin{bmatrix} 2b_4 & b_7 & b_8 \\ b_7 & 2b_5 & b_9 \\ b_8 & b_9 & 2b_6 \end{bmatrix}$

the vectors x = $\begin{bmatrix} B_\infty \\ r \\ B(t=0) \end{bmatrix}$ and d = $\begin{bmatrix} -b_1 \\ -b_2 \\ -b_3 \end{bmatrix}$

From this, the values of r, B_∞ and B(t=0) that minimize RSS can be expressed as

$$x = D^{-1} d \qquad (16)$$

Table 3. Total catch and end-of-season equivalent catch.

Season (March-February)	Total catch	Equivalent catch	Ratio
	thousand tons		
1950	6.5	4.0	1.62
51	8.4	5.4	1.55
52	42.7	26.9	1.59
53	45.6	26.6	1.72
54	28.5	17.4	1.64
55	28.0	15.3	1.83
56	36.3	21.1	1.72
57	19.9	11.6	1.72
58	9.5	6.0	1.59
59	9.0	5.5	1.63
60	7.6	4.5	1.68
61	9.9	6.3	1.57
62	8.8	5.5	1.61
63	7.2	4.6	1.56
64	12.7	8.0	1.59
65	23.7	14.1	1.68
66	66.4	40.7	1.63
67	47.7	29.7	1.61
68	40.6	27.5	1.48
69	93.0	64.3	1.45
70	107.9	78.7	1.37
71	60.5	37.5	1.61
72	59.1	40.9	1.44
73	162.6	103.3	1.57
74	142.9	95.7	1.49

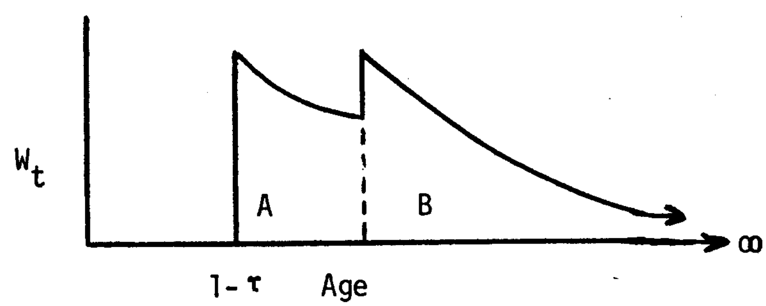
Since equation (15) only approximates the response surface, about four iterations of the above parameter estimation procedure with successively closer delineations of the trial parameter region appeared to give results precise to three significant digits in most cases. An independent test of accuracy is furnished by the previous curvilinear regression estimates. An iterative solution was run for the case of "no catches," giving results very similar to the regression estimates. Parameter estimates are given in Table 2. Unfortunately, variances and covariances are not estimated by this method.

Extended Model

The parameters used in the basic model were considered to be sufficiently accurate for use in the extended model. Three additional parameters appear in the extended model, $\emptyset$,ω and τ.

The quantity of ω is the ratio of the weight of an average pre-spawner to that of an average spawner. By dividing total weight landed by total number of fish landed for each category, average weights for these two groups can be obtained from the landings reports. The average ratio of these average weights gives an estimate of ω = 0.647 (Table 4).

The quantity $\emptyset$ is a coefficient of availability of pre-spawners. The following diagram shows how $\emptyset$ was estimated.



Fish are assumed to weight 0.647 adult units until age 1 whereupon they weigh 1 unit. The relative availability can be calculated from the following relationship between catch and the population size in areas "A" and "B."

Table 4. Mean weight data for estimation of ω and $\emptyset$.

Season	Ratio mean weight Age 0 to mean weight age 1+(ω)	Ratio catch Age 0 to catch age +1
1965-66	0.542	.0254
1966-67	0.501	.0370
1967-68	No data for southern California	
1968-69	0.765	.1740
1969-70	0.636	.2347
1970-71	0.639	.0270
1971-72	0.639	.0812
1972-73	0.815	.0852
1973-74	0.642	.0478
Mean	0.647	.0890
Standard deviation	0.103	.0764

$$\emptyset = \frac{\frac{C_o}{"A"}}{\frac{C_{1+}}{"B"}} = \frac{(C_o/C_{1+})"B"}{"A"} \tag{17}$$

Letting W_1 signify the biomass at age 1, the areas of A and B can be calculated by integrating the function describing population size as a function of time. For t=1 to t=∞,

$$W_t = W_1 e^{-(F+M-G)t} \tag{18}$$

and

$$"B" = \int_{t=1}^{\infty} W_t dt = \frac{W_1}{F+M-G} \tag{19}$$

For $t = 1-\tau$ to $t = 1$

$$W_t = \omega W_1 e^{(\emptyset F+M-G)\tau} \tag{20}$$

and

$$"A" = \int_{t=1-\tau}^{t=1} W_t dt = \frac{\omega W_1}{\emptyset F+M-G} (e^{(\emptyset F+M-G)\tau} - 1) \tag{21}$$

Substituting (19) and (21) into (17), we obtain

$$\emptyset = \frac{(C_o/C_{1+})(\emptyset F+M-G)}{\omega(F+M-G)\ (e^{(\emptyset F+M-G)\tau} - 1)} \tag{22}$$

The quantity $\emptyset$ was estimated by an iterative solution of (22), based on a historical average F of 0.03 and an average value of C_o/C_{1+} of 0.0890 (Table 4):

τ	$\emptyset$
.155	1.00
.2	0.76
.3	0.49
.4	0.35

Age 0 fish usually first appear in February, but are probably among the later fish to spawn (we have assumed March 1 is the average spawning date for all fish). Therefore, we have used a value of $\tau = 0.2$ in the model.

Stochastic Model

Equation (5) of the population growth model can be rewritten as

$$\ln B_T^* = \ln\left(B_T + R_T\right) = \ln\left(\frac{1}{B\infty} + \left(\frac{1}{B_{T-1}} - \frac{1}{B\infty}\right) e^{-r}\right)^{-1} + \varepsilon \qquad (23)$$

or more simply

$$\ln B_T^* = \ln \hat{B}_T^* + \varepsilon \qquad (24)$$

where ε is a stochastic error term with mean=0, B_T^* is surviving biomass plus recruitment, and $\hat{B}_T^*$ is predicted from B_{T-1} by the growth model. There are three principal sources of this error, variability of population processes, particularly recruitment, and error of observation of biomass at time T, and at time T-1. There is presently no definitive way to separate the components of the error term. In Figure 4, $\ln B_T^*$ is plotted against $\ln \hat{B}_T^*$ where the latter value is predicted by the growth equation and incorporates the correction for catches which were actually made. Also, the values of $\varepsilon = \ln B_T^* - \ln \hat{B}_T^*$ are plotted against $\ln \hat{B}_T^*$, showing that (1) is a good description of the relationship over the range of biomasses we have observed. The error term appears to be approximately normally distributed ($\sigma = 0.479$).

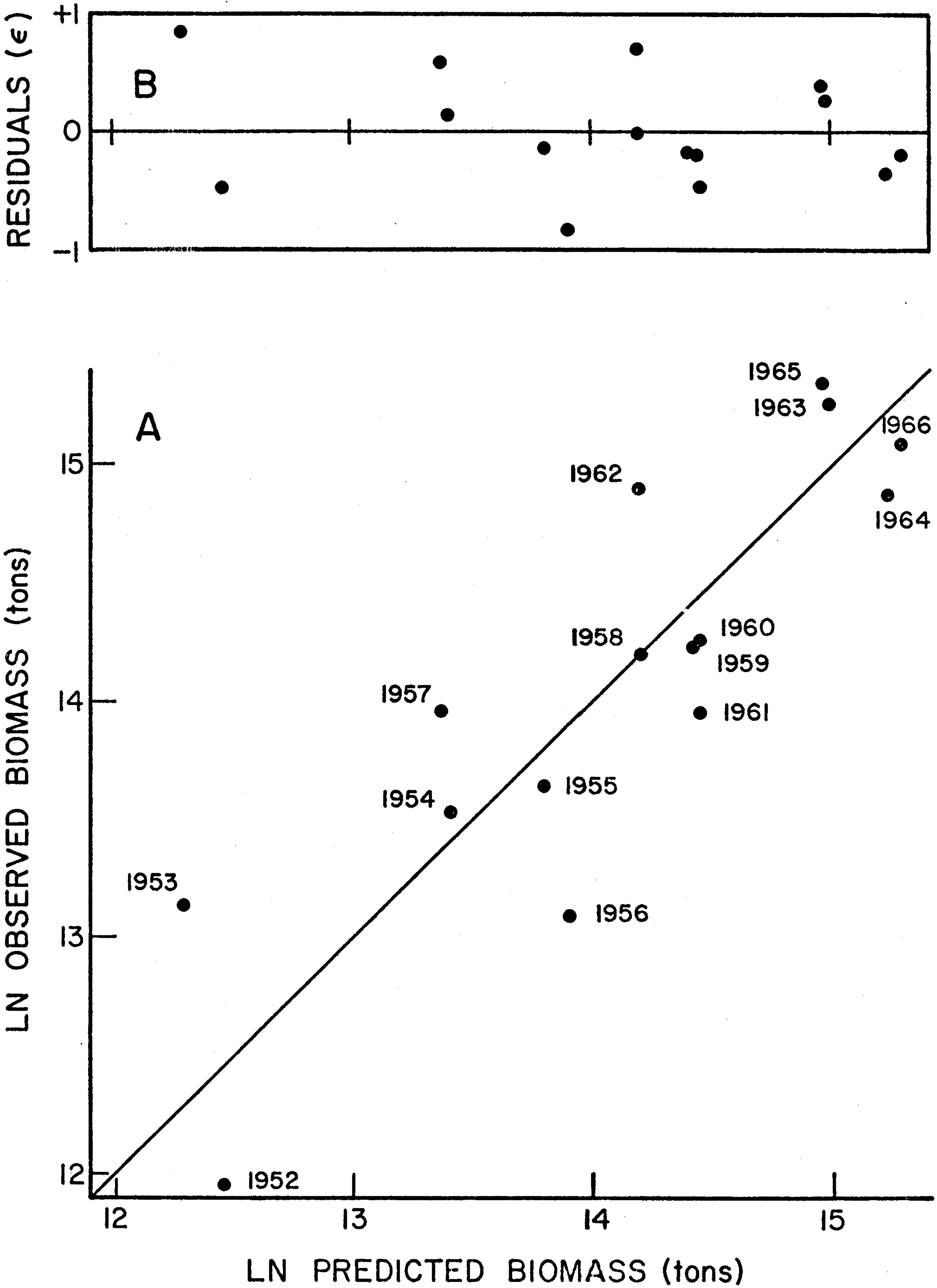
Equation (23) is equivalent to

$$B_{T+1}^* = B_{T+1} + R_{T+1} = e^{\varepsilon}\left(\frac{1}{B\infty} + \left(\frac{1}{B_T} - \frac{1}{B\infty}\right) e^{-r}\right)^{-1} \qquad (25)$$

so if there is no fishing, R_{T+1} can be obtained by the analog of (6):

$$R_{T+1} = e^{\varepsilon}\left(\frac{1}{B\infty} + \left(\frac{1}{B_T} - \frac{1}{B\infty}\right) e^{-r}\right)^{-1} - B_T e^{-(M-G)} \qquad (26)$$

Note that R_{T+1} is not actual recruitment, but apparent recruitment, since observation error of B_T and B_{T+1} is included in the stochastic error term. For this reason, apparent recruitment can become negative for low values



Appendix II. Figure 4. Comparison of predicted with observed anchovy population sizes, including a plot of residuals.

of e^{ε}. Equation (26) can be used to estimate values of ε which give negative apparent recruitment for various levels of B_T. Some example values, with their probabilities, are:

Spawning biomass B_T (1,000 tons)	Minimum ε for positive apparent recruitment	Probability $\varepsilon < \varepsilon_{min.}$ ($\sigma_{\varepsilon} = 0.479$)
1	- 1.16	0.0075
500	- 1.11	0.0102
2000	- 0.96	0.0228
4000	- 0.79	0.0495
6000	- 0.65	0.0885
10000	- 0.41	0.1977

Negative apparent recruitment in the model can be a problem if one is looking only for verisimilitude. However, apparent recruitment is an artifact of observational error in successive population size observations, so negative values can actually occur.

The extended model, which includes exploitation of pre-spawners, makes the stochastic version of the model somewhat complicated. The catch, which is determined by the harvest formula under consideration is given by equation (1). Since (11) contains the quantity R_{T+1}, we can replace this term with (26), obtaining an expression relating catch to B_T, ε and F:

$$C = \frac{F}{F+M-G} B_T \left(1 - e^{-(F+M-G)}\right)$$

$$+ \omega\left(e^{\varepsilon}\left(\frac{1}{B_\infty} + \left(\frac{1}{B_T} - \frac{1}{B_\infty}\right)e^{-r}\right)^{-1} - B_T e^{-(M-G)}\right) e^{(M-G)\tau} \frac{\phi F}{\phi F+M-G}\left(1-e^{-(\phi F+M-G)\tau}\right) \tag{27}$$

For a vector of n discrete observed biomass values $B_1, \ldots, B_n$ (in ascending order), we wish to calculate the elements of a matrix containing the probabilities that a population of observed size B_i at time T will become a population of observed size B_j at time T+1. The probabilities of each possible transition are associated with the corresponding error term ε_{ij}, which is from a hypothetically normal distribution.

Since we are given that the observed biomass at time T is B_i and the observed biomass at time T+1 is B_j, equation (10) must be

$$B_j = B_i\ e^{-(F+M-G)} + R_{T+1}\ e^{-\phi F\tau} \tag{28}$$

where R_{T+1} is given by (26). Therefore,

$$B_j = B_i\ e^{-(F+M-G)} + \left(e^{\varepsilon_{ij}} \left(\frac{1}{B_\infty} + \left(\frac{1}{B_i} - \frac{1}{B_\infty}\right) e^{-r}\right)^{-1} - B_i\ e^{-(M-G)}\right) e^{-\phi F\tau} \tag{29}$$

or

$$\varepsilon_{ij} = \ln\left(\frac{\left(B_j - B_i e^{-(F+M-G)}\right) e^{\phi F\tau} + B_i\ e^{-(M-G)}}{\left(\frac{1}{B_\infty} + \left(\frac{1}{B_i} - \frac{1}{B_\infty}\right) e^{-r}\right)^{-1}}\right) \tag{30}$$

Equation (30) can be substituted for ε in equation (27), so that F can be estimated iteratively, given B_i, B_j and C. This value of F then gives ε from equation (30).

Since B_j is a discrete population size, the probability associated with E_{ij} is approximately that given by the density function of the normal distribution, adjusted so that the sum of the probabilities for all of the B_j values for any B_i value must equal 1. Since the expected value of the error is 0, the probability can be expressed as:

$$P(B_j|B_i) = \frac{\frac{1}{\sigma\sqrt{2\pi}}\ e^{-\frac{1}{2}\left(\frac{\varepsilon_{ij}}{\sigma}\right)^2}}{\sum_{j=1}^{n} \frac{1}{\sigma\sqrt{2\pi}}\ e^{-\frac{1}{2}\left(\frac{\varepsilon_{ij}}{\sigma}\right)^2}} \tag{31}$$

Since the set of discrete population sizes has upper and lower boundaries, but the real population does not, equation (31) was modified to include the probability of events outside of the range $[B_1, B_n]$ by including the probabilities of B_j values above and below the limits of the discrete set in the probabilities of the corresponding highest and lowest value of B_j for each B_i. The discrete biomasses were chosen to be a geometric series with an element ratio of $(B_n/B_1)^{1/n-1}$ Using this ratio, values of B_j outside the range j=1,n are evaluated until the probability of B_j becomes arbitrarily small. For interpolation back to continuous population sizes, the value B_i is assumed to represent all population sizes between B_i divided by the square root of the element ratio to B_i multiplied by the square root of the element ratio.

Lumping of the probabilities at the upper and lower bounds of the set of discrete population sizes creates some distortion. In reality, the population is bounded on the lower side by 0 and is unbounded on the upper side, but the model has bounds of B_1 and B_n. This increases the probability of the population falling in the range B_1 to B_n relative to real probabilities. The extent of this bias can be assessed by comparing results from progressively wider ranges of B_1 to B_n to determine when the probabilities of observing the endpoints become negligibly small.

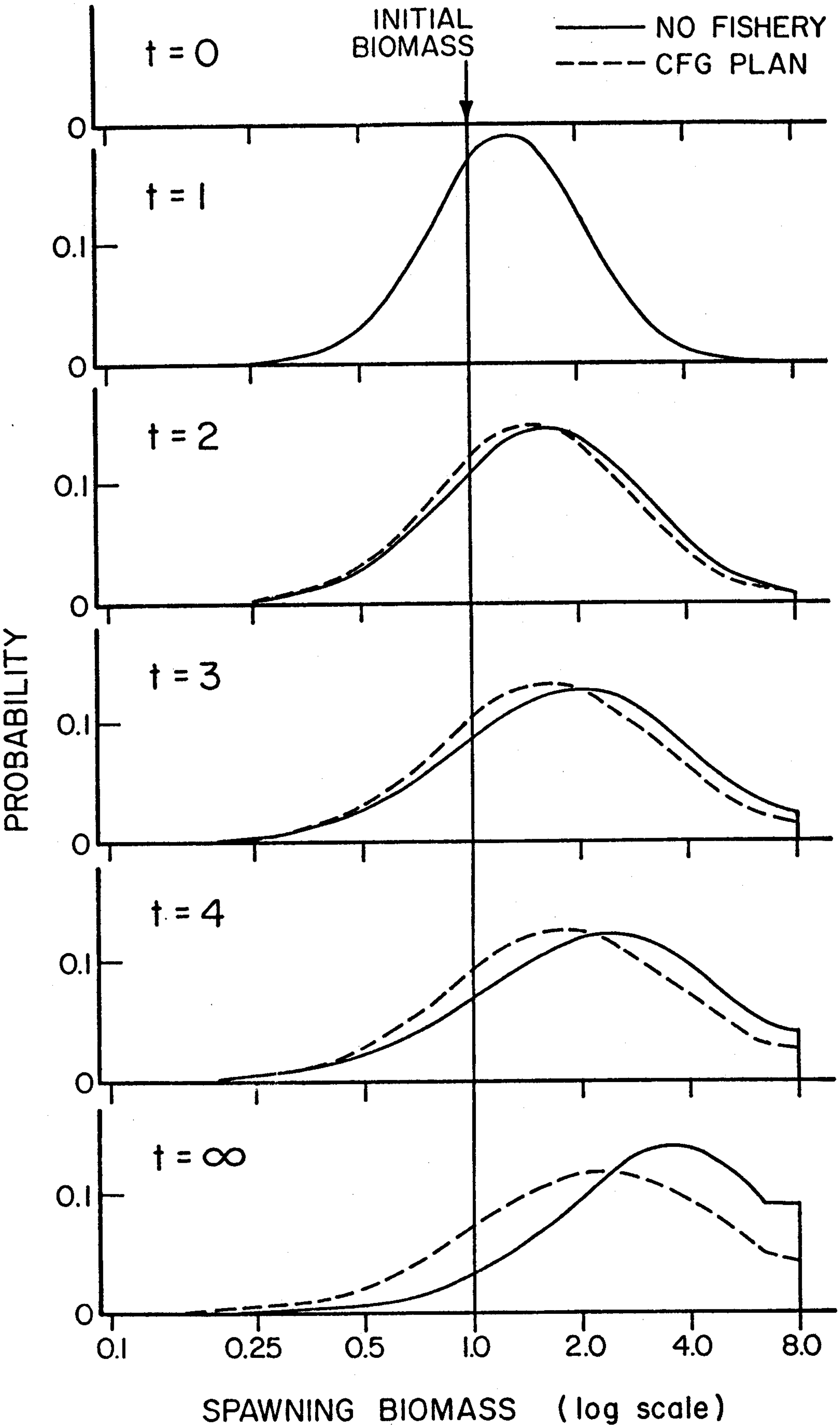
Note that the entire function of the preceding population model is to estimate transition probabilities. No manipulation or interpretation of the components of the model is attempted in obtaining those probabilities. The question to be asked is whether the model give valid estimates of those transition probabilities, and not whether the model is necessarily a good simulation of real processes. The main test we can presently perform is a comparison with the deterministic results predicted by the growth curve (Figure 3), and by the equilibrium yield curve (Figure 4.7-2). The stochastic model generally agrees with the determinstic model with regard to equilibrium points, but predicts wide fluctuations about those equilibria.

The transition probability matrix can be used for several purposes which will be individually discussed in the appropriate discussions. In general, any probability vector associated with the vector of discrete observed population sizes $\mathcal{B}$ can be multiplied by the transition probability matrix to obtain a new vector of probabilities reflecting the likelihood of observing the corresponding population sizes in the following year. For short time horizons, this multiplication can be used to investigate the probable effects of management decisions. In the case of an infinite time horizon, which could be appropriate to long-term management policy, we can find the stable probability distribution to which all beginning probability distributions tend to converge after repeated multiplication by the transition probability matrix. This stable probability distribution is that eigenvector of the transition probability matrix whose eigenvalue is 1. Actually, after about 10 multiplications by the transition matrix most initial probability vectors converge to very nearly the stable probability distribution given by the eigenvector.

Examples of Use of the Stochastic Model

In the following examples, two management plans will be compared, for illustrative purposes only. The first plan is that of "no fishery," and is characterized by a constant quota of 10,000 tons, representing the live bait fishery. The second plan is the California Department of Fish and Game plan or "CFG Plan" which allows a harvest of one-third the excess over 1,000,000 tons spawning biomass up to a maximum quota of 450,000 tons.

The first example (Figure 5) begins with an observed biomass of 1 million tons in year 0. The probabilities of observing various population sizes during the following 4 years are compared for "no fishery" and for the "CFG Plan." In both cases the average population size grows, but in the case of a fishery, the growth rate is smaller. There is a possibility that the observed population would fall to less than 1 million tons, as shown by the probability distributions. Table 5 gives comparative statistics on the two cases. Under the "CFG Plan," expected catch quotas are given based on the average of all of the possible outcomes and their probabilities.



Appendix II. Figure 5. Illustration of stochastic anchovy population growth model results. Biomass is 1.0 million tons in year 0, and predicted population size distributions are given for subsequent years.

If we wish to look farther into the future to determine the eventual distribution of probabilities that would occur for any starting point, we use the eigenvector rather than repeatedly multiplying by the matrix ad infinitum. The eigenvector (Figure 5) appears to be the final form to which the previous probability distributions are converging. Comparative statistics are given in Table 5. Using these probability distributions, we can estimate likelihoods, averages and variances for a wide variety of resource characteristics.

The eigenvector solution gives a stable probability distribution of biomasses under the quota formula which is input to the analysis. These probabilities can be interpreted as the likelihood of observing a particular population size in any given future year. Since the quota formula is based on observed population size, we can also calculate the probability of any particular quota value. Finally, since economic values can usually be stated in terms of catch (assuming the quota is taken) and biomass (reflecting catch per operating cost) expected values of economic measures such as consumer surplus (see Appendix VI) can be calculated by the expected value operator for discrete random variables:

$$E\,[X] = \sum_{1}^{n} x_i \; p\,(x_i)$$

where x_i is the quantity being averaged, and $p\,(x_i)$ is the probability of observing that value of x_i, for the n discrete population sizes being used. Variances are calculated similarly. Some examples of expected values and variances are given for the quota formula presently used by California (Table 6).

In the case of some characteristics, such as biomass, the median value may be more useful than the mean (which is influenced by rare, large values). The median can be interpreted as that value about which the variable will be larger 50% of the time, and be smaller 50% of the time. In particular, the median value is a better measure of equilibria than is the mean, as it better reflects the central tendency. Median values are given in Table 6, but a more flexible treatment can be obtained by plotting cumulative probability distributions. The median value is that where the cumulative

Table 5. Statistics for example use of stochastic population model, comparing "no fishery" with "CFG Plan" (in parentheses).

Time (years)	Expected (average) values million short tons		Probabilities	
	Biomass (B) (at beginning of season)	Catch quota	B < 1.0	B < 2.0
t = 0	1.0 (1.0)	0.01 (0.0)		
1	1.44 (1.44)	0.01 (0.151)	0.305 (0.305)	0.817 (0.817)
2	1.92 (1.80)	0.01 (0.202)	0.237 (0.265)	0.638 (0.681)
3	2.35 (2.07)	0.01 (0.230)	0.193 (0.239)	0.527 (0.608)
4	2.68 (2.26)	0.01 (0.247)	0.162 (0.221)	0.452 (0.562)
Long-term ($t=\infty$)	3.64 (2.71)	0.01 (0.287)	0.063 (0.167)	0.250 (0.459)

Table 6. Example use of stochastic population model in calculating expected values, variances (standard error^2) and median values. Quota is California plan.

Characteristic	Expected value	Standard error	Median value
Spawning biomass (10^6 tons)	2.87	2.22	2.21
Catch, assuming full quota is harvested (10^3 tons)	291	181	403

probability is 50%. Such a diagram could be useful in planning capital investments for reduction equipment, as it would be inadvisable to install a reduction capacity which would only be fully utilized in one out of ten years.

The stochastic model is also useful in searching for maximum values (or optimum values) over a wide range of candidate harvest quota formulae, or other restrictions. An example is given in Appendix VI, where the optimal reduction capacity (which maximizes return to investors) is determined for various harvest formulae. Similarly, the optimum reduction capacity (which maximizes total benefit to investors, consumers and the environment) can be determined. Such searches for maximum values must be done iteratively by systematically varying the management formulae and determining the response surface. Techniques such as described earlier in fitting the anchovy growth curve (Stauffer 1973) are appropriate for determining maxima if enough criteria for optimality can be specified.

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APPENDIX III

CALIFORNIA ANCHOVY FISHERY REGULATIONS

California Fish and Game Code (Specific Regulations)

Anchovies

Section 8180. "In any district or part of a district lying south of a line drawn east and west through Point Mugu, anchovies may be taken in any quantity for bait or for human consumption in a fresh state, or by contract with the department, for hatchery food, not to exceed 500 tons per year."

Section 8181. "Anchovies taken south of that line in waters not less than three nautical miles from the nearest point of land on the mainland shore, and anchovies taken north of that line in any waters, may be possessed, transported, sold, or otherwise dealt with in any district or part of a district south of that line."

Section 8182. "The operator of any boat engaged in taking anchovies in waters south of the line described in Section 8180 shall at all times while operating such boat identify it by displaying on an exposed part of the superstructure, amidships on each side and on top of the house visible from the air, the Department of Fish and Game registration number of the boat, in 14-inch black numerals on white background."

Section 8183. "No anchovies may be taken for any purposes in Humboldt Bay."

Section 8188. "No anchovies less than 5 inches in length measured from tip of snout to tip of tail may be purchased for any purpose except for use as bait but the allowable percentage of undersized anchovies which may be contained in any load or lot purchased shall be not more than 25 percent by weight of all anchovies in the load or lot."

California Fish and Game Code (General Regulations)

Area closures or gear regulations not specifically directed at the anchovy fisheries, but having an effect upon the harvest of this resource.

Round Haul Nets

Section 8750. "As used in this article, "round haul nets" are circle seines, and include purse seines and ring or half ring, and lampara nets."

Section 8751. "In Districts 1, 2 and 3, round haul nets may not be possessed on any boat, except in that part of District 3 lying within the boundaries of the Moss Landing Harbor District, where round haul or any other type of nets may be possessed on any boat."

Section 8752. "In Districts 6, 7, 8, 9, 10 and 11, purse and round haul nets may be used."

Section 8753. "In that part of District 16 lying north and west of a line drawn from the light on the end of the Monterey Breakwater magnetic east to the shore line, purse and round haul nets may be used to take fish other than squid, and lampara nets may be used to take squid.

In that portion of District 16 lying southerly of the Monterey Breakwater and south of a line drawn from the light on the end of such breakwater magnetic east to the shore line, lampara nets may be used from June 1 to August 31 for the purpose of taking squid."

Section 8754. "In Districts 17, 18 and 19, purse and round haul nets may be used, except that purse seines or ring nets may not be used in that portion of District 19 lying within 3 miles offshore from the line of the high-water mark along the coast of Orange County from sunrise Saturday to sunset Sunday from May 1st to September 10th, inclusive.

Purse seine or ring nets may not be used from May 1st to September 10th, inclusive, in the following portions of District 19:

(a) within a two-mile radius of Dana Point
(b) within a two-mile radius of San Mateo Point
(c) within two miles offshore from the line of the high-water mark along that portion of the coast of Orange County lying between the northernmost bank of the mouth of the Santa Ana River and a point on such coast six miles south therefrom."

Section 8755. "In District 20A and 21, purse and round haul nets may be used.

(a) Purse and round nets may be used except: (1) from sunrise Saturday to sunset Sunday, in that portion of District 20 from a line extending three nautical miles east magnetically from the extreme easterly end of Santa Catalina Island southwesterly and northerly to a line extending three nautical miles southwest magnetically from the most southerly promontory of China Point and (2) at any time during the period commencing on June 1st and ending on September 10 in each year, in that portion of District 20 from a line extending three nautical miles east magnetically from the extreme easterly end of Santa Catalina Island southerly to a line extending three nautical miles southeasterly magnetically from the United States government light on the southeasterly end of Santa Catalina Island."

Dip Nets

Section 8870. "Dip nets may be used subject to the following restrictions:

(a) In Districts 1, 1-1/2, 2, 3 and 4, dip nets may not be baited, and may not measure more than six feet in greatest breadth.
(b) In District 19, dip nets six feet or less in greatest breadth may be used. In that district dip nets may not be used within 750 feet of any pier, wharf, jetty or breakwater, except to take anchovies, squids, and sardines for bait, and to take smelt.
(c) In District 20, dip nets more than six feet in greatest breadth may not be used or possessed."

Commercial Fishing Reports

Section 8011. "Every person engaged in the business of buying, canning, curing, or preserving fish, or manufacturing meal, oil, flour, protein concentrate, animal food, or fertilizer from fish or dealing in fish, who receives fish from fishermen, other than persons engaged in the taking, transportation, or sale of live freshwater fish for bait, shall make a legible record in the form of a receipt in quadruplicate on forms to be furnished by the department.

The receipt shall show:

(a) The weight of each species of fish received.
(b) The name of the fisherman.
(c) The Department of Fish and Game registration number of that boat.
(d) The name of the recipient.
(e) The date of receipt.
(f) The price paid.
(g) The department origin block number where the fish were caught.
(h) The type of gear used.
(i) Such other statistical information as the department may require.

Section 8012. "The receipt shall also state whether the fish are intended to be sold fresh or to be canned, cured, made into fish meal or fertilizer, or otherwise disposed of. If a commercial distinction is made between different sizes or qualities of any species or variety, that shall be so stated on the receipt. The receipt shall also state what fish were taken in foreign waters, or in the high seas off another state or foreign country."

Section 8013. "The names used in the receipt for designating the species of fish dealt with shall be those in common usage, and may be designated by the department."

Section 8014. "The original signed copy of the receipt shall be delivered to the fisherman at the time of the purchase or receipt of the fish. The duplicate copy shall be kept by the dealer or person receiving the fish for a period of six months and shall be available for inspection at any time within that period by the department and the triplicate copy shall be delivered to the department on or before the first and sixteenth day of each month. On delivery of sardines, anchovies, mackerel, or squid used or intended to be used in a cannery a quadruplicate copy shall be made at the time of the original and shall be made available by the maker for delivery to an agent authorized in writing by the majority of the persons who participated in the taking of the fish, excluding the fisherman receiving the original copy. The buyer or canner upon request of such authorized agent shall notify the agent of the unloading and weighing of such fish and shall permit such agent to be present at all times during the weighing of such fish."

Title 14 of Fish and Game Commission (Specific Regulations)

145. ANCHOVY PACK. Each packing plant processing anchovies shall produce from each ton of anchovies received in his plant for canning during each calendar month not less than the following number of cans:

1 lb. tall or oval . . . . 864 cans
(864 cans are equal to 18 cases, 48 cans to case)
#10 . . . . 120 cans
(120 cans are equal to 20 cases, 6 cans to case)
1/2 lb. oval or 9 oz. oblong . . . . .1344 cans
(1,344 cans are equal to 28 cases, 48 cans to case)
1/2 lb. round . . . . .1584 cans
(1,584 cans are equal to 33 cases, 48 cans to case)
1/4 lb. oblong . . . . .2600 cans
(2,600 cans are equal to 26 cases, 100 cans to case)
5 oz. or 6 oz. round (paste can) . . . . .2133 cans
(2,133 cans are equal to 21-1/3 cases, 100 cans to case)

Any canner of anchovies desiring to pack in cans of a size or style not listed above must submit samples of the pack to the Commission, and secure the acceptable equivalent before engaging in packing such size or style of pack.

146. ANCHOVIES, SIZE LIMIT. To determine the percentage of anchovies measuring less than the minimum size limit fixed by Sections 8188-8189 of the Fish and Game Code, samples shall be taken from various portions of the load or lot measured and weighed, and the mean of the combined weights of all samples taken shall determine the percentage. Samples shall be taken in containers of not less than one gallon size approximately full of anchovies. Five (5) such samples shall be taken for loads of 20 or more tons, four (4) samples for loads or lots of from 15 to 20 tons, three (3) samples for loads or lots of from 10 to 15 tons, and at least two (2) samples shall be taken from loads or lots of less than 10 tons.

147. GRANTING AND ISSUANCE OF PERMITS TO TAKE AND USE ANCHOVIES BY A REDUCTION PROCESS. It is the intent of the Fish and Game Commission that an experimental, scientifically managed program for the taking of anchovies for reduction purposes shall continue at least through the 1970-71 season.

If during the season the maximum quota set by the commission hereafter for the Northern or Southern areas should be approached, the commission will consider an increase in the quota for the area approaching its quota.

The following shall constitute the regulations under which permits may be issued for the take and use of anchovies for reduction.

(a) Permits to take anchovies

(1) Suspension of permits. If the commission determines that the anchovy resource is being used to the point where it may tend to deplete the species or result in waste or deterioration or such resource is not being utilized in the best public interest or for other cause, it may, within not less than 48 hours, suspend all permits issued under the authority of these regulations until further notice.

(2) Size limit. No anchovies less than five (5) inches in length, measured from tip of snout to tip of tail, may be used or taken for reduction purposes, except that undersized anchovies not exceeding more than 15% by weight of all anchovies in the load or lot may be

contained in any load or lot taken, purchased or used for reduction purposes.

(3) Vessel identification. The operator of any boat engaged in taking anchovies under these regulations shall at all times while operating such boat identify it by displaying on an exposed part of the superstructure, amidship on each side and on top of the house visible from the air, the department's registration number of the boat in 14-inch black numerals on white background.

(4) Records. Vessel operators who take anchovies for reduction purposes shall keep full and accurate records of their fishing operations on forms furnished by the department. Such forms shall be filled out after each set is made and must be completed prior to the vessel's arrival at the reduction plant. Completed forms shall be delivered to the department's representative upon arrival at delivery point.

(5) Declaration of intent to take anchovies for reduction purposes.

a. The provisions of subsection (5) shall apply only to vessels taking anchovies for reduction purposes in the Southern Permit Area as described in subsection (6)(b).

b. No vessel shall be operated to take, carry, or deliver anchovies for reduction purposes unless a declaration of intent has been filled regarding said vessel in accordance with these regulations.

c. Before a vessel operator can file a declaration of intent as required by subsection (5) he must be the operator of a vessel duly registered as provided by Section 7890 of the Fish and Game Code, and must possess a valid commercial fishing license.

d. No vessel operating under the authority of a declaration of intent filed pursuant to these regulations shall take, carry or deliver anchovies for any purpose other than reduction except when taking anchovies for canning or live bait purposes as provided in subsection (5)(1) of these regulations, or when operating pursuant to an exception filed in accordance with subsection (5)(e) of these regulations. When operating under the authority of an exception, no anchovies may be taken for reduction purposes.

e. During the period for which the declaration is in force and effect, a named vessel may be used to take, carry and deliver anchovies for other than reduction purposes, if, and only if, operator files an exception in accordance with the following provisions:

   1. When the operator intends to use said vessel to take anchovies for purposes other than reduction he shall so notify the Long Beach office of the Department of Fish and Game, either by letter or telegram, prior to the commencement of fishing. This notice shall be posted or sent prior to the commencement of fishing and shall be effective only on the vessel named.

   2. The notice shall contain the following information: the calendar days for which the exception is to be effective; the purpose for which the anchovies are to be taken; and the name and registration number of the vessel.

f. Declaration of intent shall be filed with the department during normal working hours at the San Diego or Long Beach office of the department. The declaration of intent shall be filed on forms furnished by the department.

g. Each declaration of intent shall specify the vessel to which it applies. Only one vessel may be specified on any one declaration, but a qualified applicant may file separate declarations for more than one vessel.

h. Except as otherwise provided, any declaration of intent filed pursuant to these regulations shall be in force only during the open season, or if filed after the beginning of such term, for the remainder thereof.

i. A copy of each declaration filed under subsection (5) to take anchovies shall be carried aboard the vessel to which it relates and shall be exhibited upon demand to the authorized representative of any reduction plant to which said vessel is delivering anchovies and upon demand to any officer of the Department of Fish and Game.

j. No vessel which has filed a declaration of intent to take, carry and deliver anchovies for purposes of reduction and has filed no exception thereto shall place any net in the water for the purpose of taking anchovies in any unauthorized area. In the event of any violation of this section, the operator of said vessel shall be deemed in violation thereof.

k. Whenever anchovies are possessed aboard a vessel for which declarations of intent to take, carry and deliver anchovies for reduction purposes has been filled and such declaration is in full force and effect, and not then subject to any notice of exception pursuant to subsection (5)(E), it shall be conclusively presumed that said anchovies were taken and were being carried for reduction purposes.

l. Notwithstanding the other provisions of Section 147(a)(5), vessels operating under a declaration of intent to take anchovies for reduction purposes may also take anchovies for canning purposes, pursuant to the appropriate sections of the Fish and Game Code and of Section 147, Title 14, and may also take anchovies for live bait purposes, providing that all conditions, laws, and regulations pertaining to the reduction fishery are adhered to while so engaged in live bait fishing.

(6) Permit areas.

a. Northern Permit Area. The total tonnage for this area shall be 15,000 tons per season. The area shall include the waters of the Pacific Ocean between the California-Oregon border and a line extending due west (true) from Point Buchon. Anchovies taken under the provisions of these regulations may be taken in all waters of the northern permit area described above, with the following exceptions: within Districts 2, 8, 9, 11, 12, 13, 15; the waters of Bodega and Tomales Bays; that portion of District 10 lying inshore of a line beginning at Pigeon Point (San Mateo County) thence northwesterly in a straight line to the U.S. Navigation Light on S.E. Farallon Island, thence northerly in a straight line to the U.S. Navigation Light on Pt. Reyes (Marin County); that portion of District 16 lying southerly of the Monterey Breakwater magnetic east to shoreline; that portion of District 18 within 3 miles of shore in the area lying between a line drawn magnetic west of Point Estero and a line drawn magnetic west of Point Buchon; and that portion of District 18 within 3 miles of shore in that area lying between a line drawn magnetic west of Point San Luis and a line drawn magnetic west of Arroyo Grande Creek.

b. Southern Permit Area. The total tonnage for this area shall be 100,000 tons, except that for the 1975-76 season when the total tonnage shall be 150,000 tons. The area shall include the waters of the Pacific Ocean between the United States-Mexico International Boundary and a line extending due west (true) from Point Buchon. Anchovies taken under the provisions of these regulations may be taken in all waters of the southern permit area described above, with the following exceptions: within 3 miles of the mainland shore south of Point Buchon and in all districts or portions of districts where and at such times as the use of round-haul nets is prohibited; within 4 miles of the mainland shore between lines running 235° magnetic from the steam plant stack at Mandalay Beach and 205° magnetic from the steam plant stack at Ormond Beach; within the area encompassed by a line extending 6 miles 165° magnetic from Point Fermin, thence to a point located 3 miles offshore on a line 210° magnetic from Huntington Beach pier; within 6 miles of the mainland shore south of a line running 210° magnetic from the tip of the outer breakwater of Oceanside Harbor.

(7) <u>Season</u>

a. The season for taking anchovies for use by a reduction process under these regulations shall open August 1 of each year in the northern permit area and on September 15 in the southern permit area.

b. Closing date northern permit area. The season for taking anchovies in the northern permit area for use by a reduction process will close on May 15 of each year or whenever 15,000 tons of anchovies have been taken, whichever occurs first. In the latter event, the department will estimate from the current trend of catches the date on which the season's catch will reach 15,000 tons and will publicly announce that date as the closing date of the season 48 hours prior thereto, and so notify each permit holder.

c. Closing date southern permit area. The season for taking anchovies in the southern permit area for use by a reduction process will close on May 15 of each year, or whenever the quota, as set forth in sub-section (a)(6)(b) above, has been taken, whichever occurs first. In the latter event, the department will estimate from the current trend of catches the date on which the season's catch will reach the quota and will publicly announce that date as the closing date of the season 48 hours prior thereto, and so notify each permit holder.

(b) Permits to reduce anchovies.

(1) <u>Qualification of Permittee</u>. To be eligible for a reduction permit under these regulations each applicant must have the license provided in Section 8042(a) and supply proof to the satisfaction of the department that the applicant can properly unload, weigh, and utilize anchovies for reduction before any permit is issued.

(2) <u>Applications</u>. All applications for permits to reduce whole anchovies for a given season must be received by the Fish and Game Commission, The Resources Building, 1416 Ninth Street, Sacramento, California 95814, on or before the close of business on the preceding July 15.

(3) Limitation of Permit. Not more than one permit shall be issued for each plant. Permits shall not be transferred without prior authorization from the commission.
(4) Duration of Permit. Except as otherwise provided, any permit issued pursuant to these regulations shall be in force only for the time as specified on such permit.
(5) Records. The permittee shall submit daily to the nearest office of the department receipts required under the provisions of Section 8011 of the Fish and Game Code for all anchovies purchased or received that day for reduction.
(6) Plant Delivery. No reduction plant shall take delivery of anchovies from any vessel whose operator has not filed a declaration of intent required under subsection (a)(5) to take, carry and deliver anchovies for reduction purposes.
(7) Weighing of Fish Landed. No anchovies intended for use or used in any reduction plant shall be unloaded from any vessel except at a weighing or measuring device approved by the Bureau of Weights and Measures. Such anchovies shall be weighed by a public weigh-master licensed as an individual under the laws of this state and a receipt as to such weight shall be immediately issued by him to the fisherman at the time of receipt of such anchovies. Copies of such receipt shall be handled in the manner provided in Sections 8011 to 8014 of the Fish and Game Code.
(8) Fish from South of the International Boundary. Anchovies taken south of the United States-Mexico International Boundary and landed in California for reduction processes shall be included in the total quota set by these regulations for the southern permit area.

(c) These regulations shall be set forth in or attached to all permits. Permits shall be issued only upon conditions contained in the application and signed by the applicant that he has read, understands and agrees to be bound by all the terms of the permit. A copy of these regulations shall be given to every person who files a declaration of intent pursuant to these regulations.

APPENDIX IV.A.

INSTANTANEOUS BIOMASS GROWTH RATE OF A COHORT

Stauffer (1973, p. 59) gives a calculation of instantaneous rate of growth (G) where the weight-length relationship is isometric and growth in length is linear with time. The latter is a reasonable assumption based on an examination of Spratt's observed (1975) lengths at age for ages 2 and older (112, 124, 135, 145, 155). A linear regression of length on age gives

$$l_t = l_o + at$$

where $l_o = 91.4$ mm

$a = 10.7$ mm/year (r = 0.99917)

As shown in section 4.1.2., the isometric length-weight relationship

$$W = c\, l_t^{\,3}$$

is also reasonable.

The specific growth rate G is

$$G = \frac{3a}{l_t}$$

which is plotted in Figure 1.

The true average value of G for a population with given linear growth parameters and F and M can be derived by use of the calculus. For the present purposes, an approximation is sufficient: the life expectancy of an exponentially distributed variable with decay rate M+F-G is 1/(M+F-G). Since fish are assumed to enter the spawning biomass at age 1, the average

age is $1 + 1/(M+F-G)$. And since Figure 1 shows the function $G(l_t)$ to be fairly linear, we can use the approximation

$$E\left| G\left(l_t\right) \right| \doteq G\left(E\left[l_t\right]\right)$$

with l_t evaluated at average age (which ignores the variance in length-at-age).

Letting our approximate value of E[G] be denoted as $\hat{G}$,

$$\hat{G} \doteq \frac{3a}{a\left(1+\frac{1}{F+M-\hat{G}}\right)+l_0}$$

which gives the following table of values of $\hat{G}$ for various fishing rates:

F	$\hat{G}$	$M-\hat{G}$	Mean age of spawning biomass	Length at mean age
0	0.277	0.783	2.28	115.8
0.2	0.284	0.776	2.02	113.0
0.4	0.289	0.771	1.85	111.2
0.6	0.292	0.768	1.73	109.9
0.8	0.295	0.765	1.64	108.9
1.0	0.297	0.763	1.57	108.2
∞	0.314	0.746	1.00	102.1

Note that the calculation does not include a possible increase in growth rate at age due to decreased competition. These estimates only account for the change in age structure. Recent work on daily growth rings shows anchovies to be 75 to 90 mm at age 6 months (R. Methot, pers. comm.). This would suggest that Spratt's ages are somewhat greater than true age. Fishing mortality rates in excess of 0.6 are seldom encountered in this study, and in reality, true mean age will tend to vary with recruitment strengths. Moreover, M is not precisely known (MacCall 1974) and is only assumed to be a constant 1.06. For these reasons, we have used a constant value of 0.8 for the quantity M-G, which greatly simplifies the calculations and should be sufficiently precise for our purposes.

References

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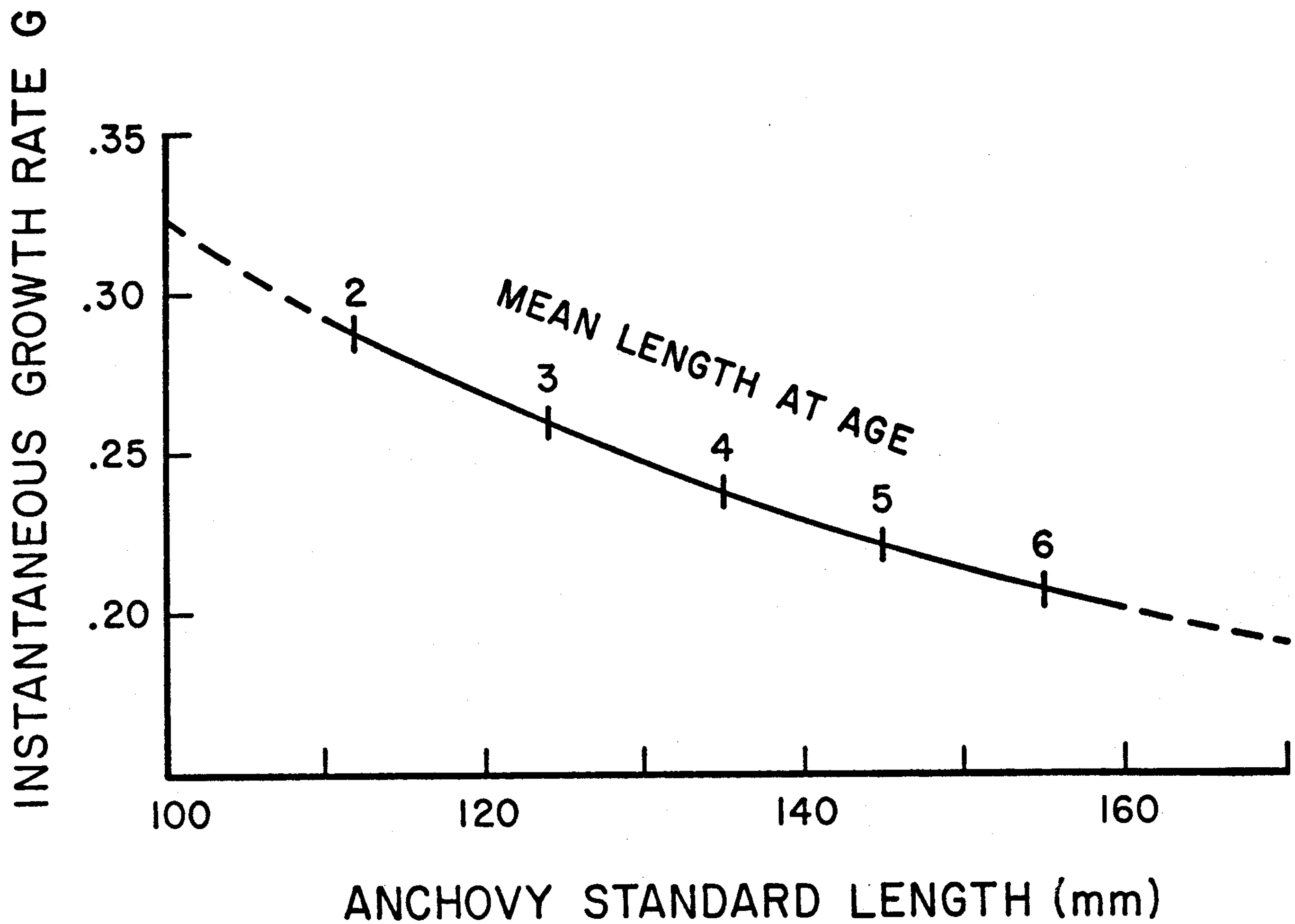

Appendix IV.A. Figure 1. Instantaneous growth rate as a function of fish length.

APPENDIX IV.B.

YIELD PER RECRUIT

A simple Beverton and Holt yield per recruit model using isometric growth (Gulland 1969, p. 107) was used to examine this aspect of optimal fishing pressure and age at entry. The following parameters were used:

natural mortality M = 1.06 (MacCall 1974)

von Bertalanffy growth L_∞ = 165.52 mm (Spratt 1975)

$k = 0.2987$ "

$t_o = -1.714$ years "

condition factor (isometric) $a = 1.015 \times 10^{-5}$ g

The yield per recruit isopleth diagram (Figure 1) gives yield in grams per fish alive at age 0.5. The bottom of the isopleth diagram is not accurate due to the distortion imposed by $t_o = -1.714$, but these very young fish are not available to be caught in any case. Yield per recruit considerations alone would suggest that anchovies should be fished very young and very hard.

The population model puts certain restrictions on this relationship due to the reduction in spawning biomass, and therefore spawning potential, if fishing mortality were high.

The yield per recruit isopleth diagram (Figure 1) gives yield in grams per fish alive at age 0.5 years. Using the model in Appendix II, the yield curve (τ = 0.2) given in Figure 4.7-2 was solved for equilibrium levels of fishing mortality rate by an iterative solution of equation (2) in Appendix II. From the population growth model, the effort at which MSY occurs (F_{MSY} = 0.41) and effort at which extinction of the population would occur (F_{max} = 1.02) show that a large portion of the yield per recruit isopleth diagram is of little practical interest. Optimal effort is certainly less than F_{MSY}. The isopleths at age of entry less than 1 year are very unreliable, since the von Bertalanffy growth curve does not indicate true growth during the first year of life. Moreover, these very young fish are not available to be caught in any case. Therefore, the diagram is useful for ages 1 and older.

Based on yield per recruit alone, the best strategy would be to fish as hard and as young as possible. The population model restricts this strategy, since the spawner-recruit relationship implied in the growth history is a more limiting factor. As shown in the population model, fishing 0.2 years before age 1 results in a lower MSY than would be obtained by beginning fishing at age 1. Therefore, yield per recruit is not an important consideration in the anchovy fishery.

References

Gulland, J.A. 1969. Manual of methods for fish stock assessment. Part I. Fish population analysis. FAO (Food Agric. Organ. U.N.) Mar. Fish. Sci. 4: 1-154.

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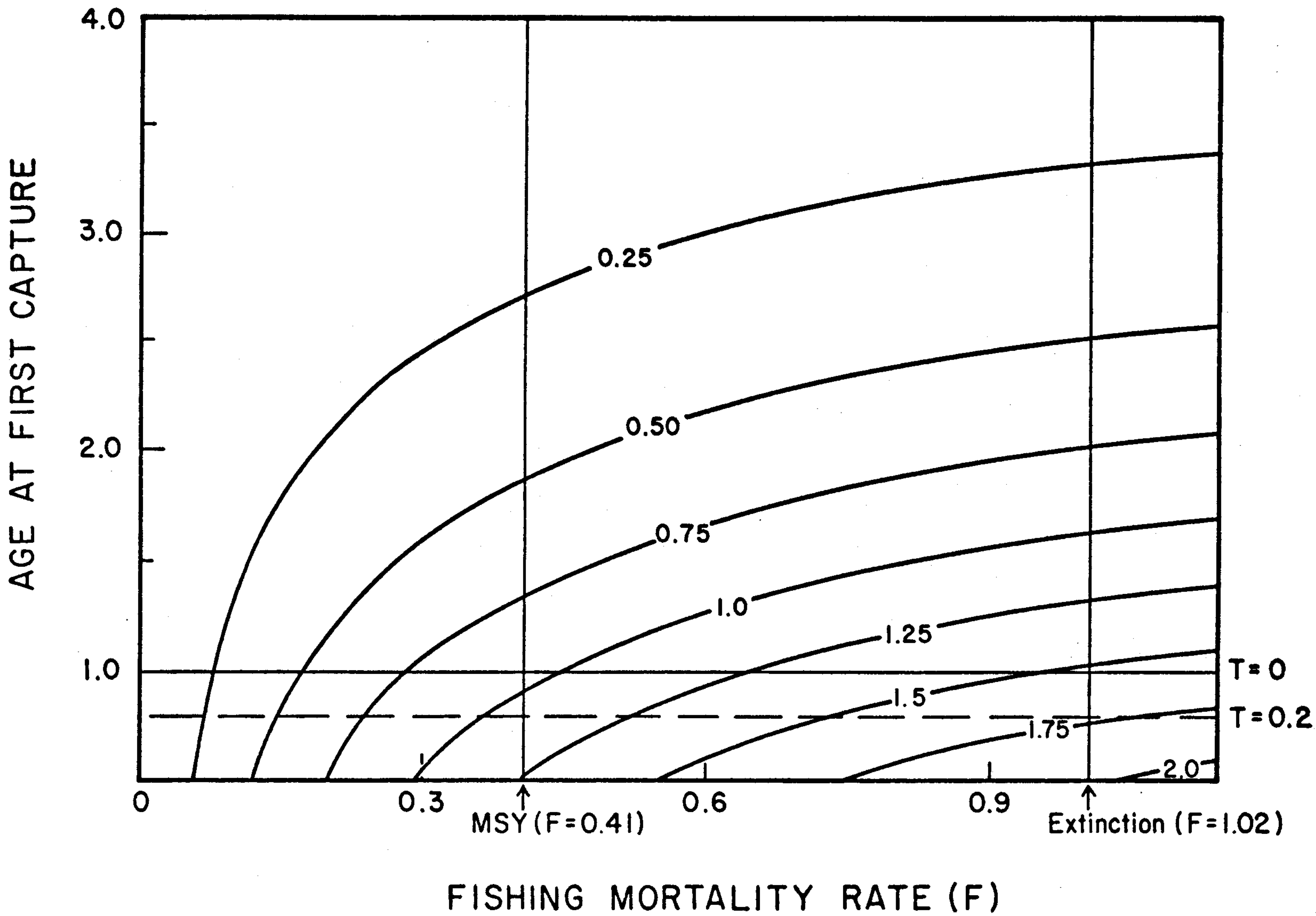

Appendix IV.B. Figure 1. Yield per recruit isopleth diagram for northern anchovy, based on von Bertalanffy growth.

APPENDIX V

NOTATION

a	linear growth rate in length
A	a constant denoting exponent value at time = 0 in the logistic growth equation
AM	abbreviation for arithmetic mean
b_i	multiple regression coefficients
B	biomass
$B(t=0)$	biomass at time 0 (1950) in the logistic growth equation
B'	population growth rate, the first time derivative of biomass
B^*	surviving biomass plus recruitment
$B\infty$	asymptotic biomass in the logistic growth equation
$\mathbb{B}$	a vector of discrete values of biomass
C	catch
cov	covariance
E	expected value operator
ε	stochastic error term
F	instantaneous rate of fishing mortality
G	instantaneous rate of somatic growth in weight
GM	abbreviation for geometric mean
k	von Bertalanffy growth rate constant
l	length
l_o	initial length
$L\infty$	von Bertalanffy asymptotic maximum length
M	instantaneous rate of natural mortality
n	number of items
$\emptyset$	availability, as a fraction of F for fully recruited fish
$P(\mathbb{B}_j \mid \mathbb{B}_i)$	the conditional probability of observing biomass $\mathbb{B}_j$ at time T+1, given that the observed biomass at time T is $\mathbb{B}_i$
r	intrinsic rate of increase, growth rate parameter in the logistic equation
R	recruitment
R^*	recruitment projected τ years back in time

RSS	abbreviation for residual sum of squares
t	time of observation
t_0	von Bertalanffy age at length zero
T	annual reference date, March 1 of each year
τ	length of time that pre-spawners are partially available to the fishery
V	variance
W	weight
ω	mean weight of available pre-spawners

APPENDIX VI

ECONOMIC ASPECTS OF THE ANCHOVY FISHERIES

Introduction

This appendix is designed to provide a more detailed review and analysis of the economics of anchovies than could reasonably be included in the main body of the Anchovy Plan. Much of the material is pertinent to the description and evaluation of the commercial reduction fishery. This emphasis should not be construed as a bias towards commercial rather than recreational interests. The commercial fishery is more easily subjected to quantitative economic analyses, however, and the resulting analysis will involve less philosophical and subjective uncertainty than would an analysis of either the live-bait fishery or the recreational fishery (for predator species). Also, the primary focus of the economic analysis will be the annual harvest quota policy, which, as proposed in the Plan, does not affect the allowable take of live-bait. The availability of live-bait, moreover, is substantially assured by the area restrictions, size limits, and seasonal closures proposed for the reduction fishery.

The minor anchovy fisheries for frozen bait, fresh human consumption, and canning are also largely ignored in the economic analysis. Specific provisions of the proposed management measures should assure the continuance of these fisheries at current levels. Of most importance, therefore, is the development of a defensible, quantitative economic assessment of the proposed alternative harvest quota policies for the reduction fishery. The economic values of the reduction fishery can then be balanced against potential socio-economic or ecological harm that might accompany an increased commercial harvest of anchovies.

General Background

Industrial fishery products are created by the rendering of whole fish, fish scrap and offal. The most prevalent production technique is the wet-rendering process, which, as described by Alverson and Broadhead (1971), involves four steps:

1. The raw fish or fish offal protein is denatured by steam cooking.
2. The cooked fish is pressed in order to separate a substantial part of the water and oil.
3. The pressed fish (press cake) is dried in a rotary drier.
4. The dried cake is ground to produce a meal, which is brought to a point of stability by natural oxidation or by the addition of an antioxidant.

The liquid separated from the cake in the pressing process, called stickwater or press water, contains valuable oil, vitamins, water-soluble proteins, and other nutritionally useful elements. The fish oil may be separated from the water by centrifuge, and the remaining water recovered for production of solubles. Evaporation of excess water brings the solubles to about 40-50 percent solids. The resulting soluble product may be sold separately or it may be returned to the meal which, after further drying, is termed whole meal.

The resulting meal has a high level of metabolizable energy (70-74 percent) and such nutritional elements as riboflavin, pantothetic acid, niacin, choline and several amino acids. Because of its higher concentration of the amino acids lysine (4.7 percent in anchovy meal compared to 2.96 percent in soybean and 1.7 percent in cottonseed meals) and methionine (2.0 percent in anchovy meal as opposed to .62 percent in soybean and .64 percent in cottonseed meals), fish meal is a particularly useful complement to vegetable protein meals as a constituent in high-protein animal feeds. The higher concentrations of essential amino acids in fish meal and the small amounts of calcium and phosphorous as well as other nutritional elements, promote fast growth in poultry and fish.

The yield of protein from raw fish depends upon the condition of the fish when entered into the reduction plant and upon the anatomical characteristics of the fish species used. Fresh anchovy, for instance, generally yields 64-68 percent protein, while menhaden generally yields about 60 percent protein. Meals produced from fish scrap and offal yield lower amounts of protein. Tuna meal, for example, once contained about 60 percent protein; but, as the tuna canners found lucrative markets for pet food and developed efficient methods of stripping all usable meat from the fish carcasses for use in pet food, the protein content dropped to 55 percent and is recently reported to be as low as 48 percent on occasion. When fish are caught for reduction they should be delivered within 12-24 hours depending upon the ambient water temperatures. The warmer the storage temperature and the longer the fish are held prior to reduction the more protein is lost through natural autolysis (Paul Farr, pers. comm.). During the recent 5-year period, 1971-75, the U.S. anchovy reduction plants have averaged .174 tons of meal for every ton of raw anchovies landed for reduction.

The oil yield from fish reduction varies considerably depending upon the amount of fat stored in the fish. For anchovies, fat content and oil yield tend to be highest prior to spawning activity. The oil yield varies seasonally, but also deviates considerably from the typical seasonal pattern in some years. Normally the yield of oil is 18-20 gallons per ton of raw fish in September, but may drop to 2-5 gallons/ton in February, March and April. During the 5-year period, 1971-75, the California reduction plants have averaged 76.8 pounds of oil per ton of anchovies landed for reduction (equivalent to 9.9 gallons/ton).

Demand and Prices for Anchovy Products

The annual harvest quotas of the anchovy management plan will influence the available supplies of anchovy reduction products. To evaluate the economic effects of any harvest policy, therefore, it is necessary to examine the impact of the prospective harvest quotas on the markets for fish reduction products generally and on the West Coast markets in particular. A conceptual framework for this examination is provided by the economic theory of competitive markets. The theory asserts that for any traded good there is a demand schedule indicating the rate of purchases that will occur at any market price. The well-known "law of demand" further asserts that the rate of purchases (i.e., the quantity demanded) will be negatively related to the prevailing market price. Put simply, the demand curve (as depicted in Figure 1) slopes downward to the right. A prime objective of quantitative demand analysis is the estimation of this demand curve.

Market prices, according to economic theory, are determined by the balancing of demand and supply. For smaller supplies, this balance occurs at higher prices; for a larger supply the balance occurs at a lower price. It can be predicted, therefore, that the management of anchovy harvests will affect market prices. Thus, quantitative analysis of demand for anchovy reduction products should contribute to our understanding of how the market prices are likely to be affected by the harvest policy. Furthermore, the demand analysis will assist in assessing the degree to which the needs and desires of producers and consumers will be satisfied by the production allowed under the anchovy management plan. Ultimately, the economic value of the anchovy harvest is contingent upon the need for anchovy products in the production of various end-products for consumers. As a general rule, there are other products in competition with any intermediate good such as anchovy meal or oil, and the supplies or prices of these competitive goods will determine to some extent the level of demand for anchovy products. Accordingly, a quantitative analysis of demand must consider the degree to which other products are substitutable for anchovy products and must estimate the probable effect of variations in supplies of substitute products on the demand for anchovy products.

Of the three products, fish meal, fish oil and fish solubles, only the meal markets have been subjected to quantitative analysis in recent years (see Havlicek and Ccama 1977; Spangler 1971). General descriptions of world fish meal markets, and technical discussions of all fishery industrial products, however, provide additional useful background material for the analysis of demand and prices (see Alverson and Broadhead 1971; Kolhonen 1974; and Karrick 1963). Narrative accounts and data on production and prices are issued regularly by the U.S. Department of Commerce, National Marine Fisheries Service (NMFS) through its current Economic Analysis series and by the Food and Agricultural Organization (FAO) of the United Nations through its annual Commodity Review and Outlook series. The analyses, descriptive materials, and data series provided by these papers and bulletins were reviewed and combined with additional information from industry spokesmen in southern California in analyzing the demand for anchovy products.

World Markets

Fish meal is traded internationally with the major exporting nations of Peru, Norway, South Africa, Chile, Denmark and Iceland, supplying substantial quantities to the major consuming nations of the United States, the Federal Republic of Germany, the United Kingdom, Poland, Italy and Japan. As indicated in Table 1, the quantity of fish meal being produced annually increased from around 2.2 million tons in 1960 to 6.0 million tons in 1970 and then declined to 4.8 million tons in 1975. Much of the increase and subsequent decrease was related to the growth and decline of the fish meal industry in Peru. Also shown in Table 1 are the estimated worldwide annual production figures for soybean and other vegetable oil cake meals. World production of oil cake meals has shown a roughly uniform rate of increase since 1960.

The most common use of fish meal worldwide is as a protein supplement in animal feeds, primarily poultry feed. The meal is combined with vegetable protein meals, grains and other nutritionally important ingredients to form a high protein feed. Feed mixers supplying major poultry growers employ professional nutritionists to formulate the animal feeds such that all major nutritional needs of the fed animals are met at lowest cost. This means that a target nutritional profile (in terms of calories, amino acids, vitamins, minerals and so forth) providing the fastest growth of the animals is set and that each potential ingredient is analyzed for its nutritional contribution to the mixed feed. Depending upon the prices at which the ingredients can be bought, more or less of a given ingredient will be included in the formula. Fish meal generally constitutes 2 to 10 percent of the formula. When more than 10 percent fishmeal is used it tends to imbue the animal flesh with a fishy flavor. At less than 2 percent, the fish meal may fail to contribute significantly to nutrition and growth.

United States feed producers have used advanced least-cost formulations for many years, while Western Europeans seem to have adopted the least-cost methods more recently. It can be expected, therefore, that low, worldwide prices for fish meal will induce users to approach the maximum 10 percent of meal in feed mixes. Conversely, an increase in price will induce a relatively rapid substitution of other protein supplements. Also, when the price of fish meal is sufficiently high relative to those of other protein supplements, some feed mixers will abandon the use of fish meal entirely, even at the sacrifice of growth rates in the fed animals.

World fish oil exports are concentrated in the major fish meal producing nations of Peru, Japan, Denmark, Norway, Iceland, South Africa, and the United States. Both Japan and the United States tend to export much of their fish oil production while being net importers of fish meal. The major importers of fish oil are the Netherlands, the United Kingdom, and the Federal Republic of Germany.

World production of fish oil, mainly as a by-product of fish meal production, was 2131 million pounds (FAO, 1976) in 1975. World fish oil exports in 1975 were only 12% of the world vegetable oil exports (Table 5). According to Fineberg and Johanson (1967), over 75% of all fish oil produced is used for edible purposes. In Europe, fish oils are used in consumable products such as margarine, shortening, and cooking oils. For consumable use, the major substitutes for fish oil are soybean, peanut, sunflower, safflower, cottonseed, palm and olive oils, as well as butter and lard. Fish oil is refined and de-odorized for consumption use, and thus is highly substitutable with vegetable oils.

The use of fish oils for human consumption in the United States is not permitted by the Food and Drug Administration. According to Fineberg and Johanson (1967), fish oil is considered to be an unacceptable consumption product in the United States because the raw materials used in the reduction process are not completely edible. According to Gryer (1963), fish oil is used domestically in various industrial products such as paints and varnishes, linoleum, leather treatments, printing inks, lubricants and greases. The major competing oils for industrial use include linseed, soybean, castor, safflower and tung oil. U.S. fish oil production was only 2% of vegetable oil production in 1976. For many industrial uses, the special qualities of fish oil make its use prefered to the use of competing vegetable oils.

The status of fish protein concentrate (FPC) in the future will probably greatly affect the world market situation for fish oil.

Because fish solubles are unimportant in world trade, the Food and Agriculture Organization does not report separate production or export/import statistics for meal and solubles. Producers in Peru tend to add the condensed fish solubles back into the meal. This increases the yield of meal by 15 to 20 percent (Alverson and Broadhead 1971, p.1). It is assumed, therefore, that fish solubles do not constitute a significant item of world trade.

The existence of a major world market in fish meal and oil has an important implication for the U.S. industry. Domestic supplies are subject to the instabilities of foreign fisheries. Imports from Peru, in particular, have varied widely due to fluctuations in the abundance of Peruvian anchoveta. During the 1960's domestic imports of Peruvian meal grew steadily to a peak of 635.9 thousand short tons in 1968, dropped to 218.1 in 1969 and to 153.1 thousand tons in 1970. Imports increased to 352.2 thousand short tons, only to collapse once again to 41.8 and 29.4 thousand tons in 1973 and 1974, respectively. When foreign sources of supply increase substantially, domestic meal prices tend to decrease and, conversely, contractions in foreign supply lead to increases in domestic meal prices.

United States Market for Fish Meal

As previously noted, fish meal and solubles are consumed in the United States for protein feed mixes. The national supplies of high-protein feed for the years since 1955 are listed in Table 2. Supplies of oilseed meal and total high-protein feed exhibit moderately rising trends while fish meal and animal protein meals generally exhibit some annual fluctuations but no general growth over the last 20 years. It is significant that fish meal constitutes but a small portion of the available total supplies. The importance of fish meal for the poultry feed industry, however, belies its relatively insignificant portion of the total national supply of protein meals.

The various types of meals generally trade on a protein-equivalent basis. That is, a comparison of two meals containing different protein concentrations is accomplished by multiplying the amount of each meal (product weight) by the percentage of protein in the meals. Consequently, total supply of fish meal is best expressed as the amount of protein supplied rather than as the total product weight of the various meals. The total supply of fish meal protein and the supplies of the various meals in the United States during the last two decades are shown in Table 3. Annual average prices for various fish meals and for domestic soybean meal are listed in Table 4, where the average price per unit protein in fish meals reflects the national average price per unit protein.

The demand for fish meal in the United States is related to the price of meal and the price of the most common substitute for fish meal, soybean meal. If the economic theory of competitive markets is a reasonable model of market behavior for protein feeds, then it is expected that, on the average, larger domestic supplies of fish meal and lower soybean meal prices would be associated with lower fish meal prices. To investigate this proposition the average price per unit protein in fish meal and in soybean meal were deflated and the following regression equation was computed (t-values in parentheses):

$$\underset{}{P_m} = \underset{(4.641)}{1.97} - \underset{(-4.245)}{.0034}\ FMP_{U.S.} + \underset{(12.695)}{1.177} \cdot SOYBPR,$$

where the dependent variable, P_m, is domestic average fish meal price per unit protein, $FMP_{U.S.}$ is fish meal protein-equivalent apparent consumption, and SOYBPR is domestic average soybean meal price. The squared multiple correlation coefficient (R^2) has a highly statistically significant (F-statistic with 19 and 2 degrees of freedom is 93.5) value of .908. Also, the three regression coefficients are significant by the one-tailed t-test. (A t-value of 1.75 is required for 95% confidence.) Both of the prior expectations from market theory are supported by this statistical evidence. The negative coefficient for fish meal protein quantity indicates that greater supplies of meal tend, on the average, to depress prices. Also, the predicted positive effect of soybean prices on fish meal prices is reflected in the positive value of the soybean price coefficient.

The regression equation is depicted in Figure 1, where a change in soybean meal price is shown to cause a substantial shift in the demand curve for domestic fish meal. In only 1 year, 1973, was the price of domestic soybean meal substantially above its typical range. Also, in 1973, the price of fish meal protein was approximately double its more usual level. Thus, any wide swings in vegetable meal prices are expected to encourage a greater demand for fish meal. Given relatively fixed fish meal supplies, furthermore, any dramatic increase in demand will be reflected in higher prices.

Because domestic anchovy meal is consumed primarily in California and neighboring states, the existence of a relatively isolated and independent market for meal produced from the northern anchovy is postulated. The California market is isolated from the midwestern markets by distance and freight charges. The cost of transporting a ton of soybean meal from Decatur, Illinois to California markets is approximately \$45.30. Also, there is no significant California soybean crop, but there is a large cottonseed crop. Thus, West Coast poultry growers are unlikely to buy either East or Gulf Coast fish meal or midwestern soybean meal unless local supplies of fish meal and cottonseed meal are either in short supply or exceedingly expensive. Another pertinent factor is the relatively low concentration of lysine in cottonseed meal as compared to soybean meal. To a feed mixer using local supplies of cottonseed meal in California, the addition of fish meal is quite important because the best alternative source of supplemental lysine and methionine (i.e., soybean meal) is available only at prices inflated by transportation charges. Finally, the production of feed mixes for freshwater and anadromous fish species is heavily localized in the West Coast States, and anchovy meal (or a high-protein alternative such as herring meal) is preferred to the tuna meal or menhaden meal. According to industry sources, about 20% or 3,500 tons of the annual anchovy meal production is sold to fish feed manufacturers located primarily in Utah and Idaho.

As a consequence of the foregoing factors, the West Coast market for anchovy meal should operate somewhat independently. The independence from the national market should be reflected in price movements of California-produced meal relative to national average prices. The price of California meal should be relatively higher when California meal is in short supply, and should be relatively lower when local supplies are abundant. The following regression equation provides statistical support for these expectations.

$$P_{CALFM} = \underset{(4.56)}{1.082} - \underset{(4.83)}{.0048}\ CFMP;$$

where the dependent variable, P_{CALFM}, is the price of California fish meal (tuna and anchovy meal) per unit protein divided by the U.S. average price, and the independent variable, CFMP, is annual production of tuna and anchovy meal in California in protein-equivalent units. The squared multiple correlation coefficient (R^2) has a statistically significant value of .538 (the F-statistic with 20 and 1 degrees of freedom is 23.29).

The regression equation plotted in Figure 2 represents the California demand for local fish meal. As expected, larger local supplies of fish meal tend, on the average, to depress local prices relative to the national average price for fish meal. If the California price were to fall way below or way above the national average fish meal protein price, there would be definite economic incentives for inter-regional shipments of meal. A widening of the market would attenuate the relative price movement for California-produced fish meals. It is not surprising, therefore, that the California price relative to the U.S. average price falls in the narrow range of .8 to 1.1.

Market for Fish Oil

The demand for fish oil was investigated for both the United States market and the world market. These markets are distinct; the U.S. market demands oil only for industrial use, while the world market demands a majority of fish oil for consumption use. Various vegetable oils comprise the major substitutes for fish oils, as has been previously noted. The world market production, exports and prices of fish and vegetable oil for 1958-1975 are listed in Table 5. Included in the vegetable oil category for world exports are the following oils, all of which are substitutes for fish oil to some degree: soybean oil, castor oil, cottonseed oil, groundnut oil, linseed oil and palm oil. World exports of fish oil equalled 12% of vegetable oil exports in 1975. The production and price figures for fish and vegetable oil for the United States are listed in Table 6. The vegetable oils included for U.S. production are soybean, cottonseed, and linseed oil. The U.S. share of total fish oil production is relatively small, approximately 10% of world production. It can be postulated that the U.S. fish oil market will have little influence on the much larger world market.

The demand for fish oil in the United States is not determined in isolation by the U.S. price and production of fish oil and vegetable oils. The price of fish oil will most likely be determined in the world market. The world market is expected to behave according to the economic theory of competitive markets, with the price for fish oil being determined by the supply of fish oil and the price of vegetable oil substitutes.

The U.S. demand for fish oil was investigated using regression analysis and it was found that, as expected, U.S. fish oil production and price were not significantly related. The U.S. fish oil production and price were also not significantly related to U.S. vegetable oil prices. This was true both for total U.S. fish oil production, and for U.S. anchovy fish oil production. This is not surprising since the U.S. fish oil market is considerably smaller than the world market. The average weighted price, both actual and deflated, of U.S. fish oil fluctuates from year to year, but these fluctuations do not appear to be statistically related to domestic production fluctuations.

The world demand for fish oil was also investigated for the years 1950-1975 using regression analysis. The average weighted prices of fish oil and vegetable oil were deflated, and the following inverse demand equation was estimated (t-values in parentheses):

$$FOP_{wld} = \underset{(1.337)}{.0609} - \underset{(-3.457)}{.00008605}\, FOX_{wld} + \underset{(5.5315)}{.15129}\, VEGP_{wld}$$

where FOP_{wld} is world fish oil average weighted export price; FOX_{wld} is world fish oil exports, and $VEGP_{wld}$ is world vegetable oil average weighted price. The squared multiple correlation coefficient (R^2) with a significant value of .7117, indicates a good fit for the regression equation (F-statistic with 23 and 2 degrees of freedom is 28.4). The regression coefficients for the two parameters are statistically significant at 95% confidence (t-value of 1.71 required). The constant term is insignificant, but this is not important to this analysis. This regression equation supports the contention that world fish oil price and quantity are related. The world demand for fish oil fits the economic model for competitive market behavior, that is, greater supplies of fish oil have a negative effect on prices. The regression results also support the hypothesis that substitute vegetable oil prices are positively related to fish oil prices. Thus, it is shown that fluctuations in the world fish oil production will result in corresponding fluctuations in price.

As was stated previously, a similar relationship between U.S. fish oil price and quantity was not observed for the U.S. market. However, when the relationship between U.S. fish oil price and world fish oil production and world vegetable oil price was investigated for the years 1966-1975, significant statistical results were found. The following equation represents this relationship (t-values in parentheses):

$$AFOP_{us} = \underset{(2.2056)}{.12207} - \underset{(-2.1825)}{5.328\ FOQ_{wld}} + \underset{(5.746)}{.0814\ VEGP_{wld}}$$

where $AFOP_{us}$ is anchovy fish oil average weighted price, U.S., FOQ_{wld} is world fish oil production and $VEGP_{wld}$ is world vegetable oil average weighted price. The squared multiple correlation coefficient (R^2) indicates a statistically significant relationship with a value of .854 (F-statistic of 2 and 7 degrees of freedom is 20.477). All of the regression coefficients are statistically significant at 95% confidence by the one-tailed t-test (t-value of 1.89 required). This result indicates that there is a statistically significant relationship between U.S. anchovy fish oil price, world fish oil production and world vegetable oil price. The relationships are of the predicted sign--a negative relationship with world fish oil production and a positive relationship with world vegetable oil price. This indicates that any fluctuations in the world supply of fish oil or fluctuations in world vegetable oil prices will cause the domestic anchovy fish oil price to fluctuate.

Production Costs

The costs of producing anchovy reduction products occur at both the harvesting and processing stages. The harvesters incur capital costs related to the purchase and maintenance of fishing vessels, as well as operating costs related to the amount of fishing done. Similarly, processors' capital costs are related to the size and number of reduction plants in place. Operating costs for the reduction plants are related to the amount of time the plants are actually utilized to produce meal, oil and solubles. Quantitative estimates of these costs are derived from a recent study of the anchovy and jack mackerel fisheries by Earl R. Combs, Inc.

The fleet of vessels fishing for anchovy is very diverse both in vessel size and in proportion of the fishing year devoted to fishing for anchovy. Rather than estimate actual vessel operations and operating costs in great detail for the variety of vessels and fishing strategies used in the existing fleet, the simplified approach used here estimates a reasonable approximation to the minimum fishing costs for larger vessels. These cost estimates are based on information collected by Earl R. Combs (1977) from a sample of fishing vessels landing primarily anchovies in southern California. This procedure has both advantages and disadvantages. The main advantage is that the cost figures will represent a reasonable estimate of the real economic costs of harvesting without being overly complicated by considerations of vessel size, time spent in various fisheries, and differing age and resulting depreciation charges among vessels. The total costs under this simplified scheme consist of an operating cost per ton of anchovies landed and a capital cost that is related to the number of vessels fishing anchovies.

The obvious disadvantage of the simplified characterization of harvesting cost is that it largely ignores the particular circumstances in which many vessels may be found. Some vessels, for instance, may fish only occasionally for anchovies when catch rates are very good or when there are temporarily no alternative fisheries to occupy them. In such cases, it is possible that the vessels will harvest anchovies at a lower or higher real cost per ton than is estimated for the larger, efficient vessels represented by the simplified cost estimate. The assumption behind the cost estimate is that the vessels will devote all or most of the available anchovy fishing season to fishing anchovies. According to Combs (p. 35), the breakeven cost per ton for a large, efficient wetfish vessel is $24.58. This cost corresponds to a vessel capable of landing 130 short tons of anchovies per trip, with each trip in the reduction anchovy fishery lasting one night. With a 32-week fishing season, and assuming that no fishing occurs during 1 week out of every 4 (due to the bright moon), there will be 24 weeks of fishing. For the entire fishing season, the vessel catches 7,513 tons of anchovies, for a total fishing cost of $184,670, or a weekly cost of $7,695. These figures are, of course, averages. Better fishing or higher prices would yield more income and, because of the crewshare arrangement, higher apparent costs.

The crewshare system essentially splits the operating income net of variable trip costs. Although this is a reasonable and accustomed practice in fishing, it complicates the assessment of fishing costs. With fixed wages, the labor costs of producing a commodity are straightforward, but the sharing system used by fishing vessels allows both labor and management (i.e., crewmen and vessel owner/operators) to share in profits and losses. When vessels are extremely successful, the crew shares the profit by receiving payments over and above the minimum amount needed to secure its services. Conversely, when fishing is very poor, the crew bears much of the financial burden through lower payments. It is not necessarily true, therefore, that the actual payments made to crew members reflect economic costs of labor, a cost which is approximated by the income earned by other workers of similar ability and level of training. Actual crew payments may contain shares of profits and losses which are relatively transitory. The estimate of fishing costs for anchovies should reflect the amount that crews must be paid in order to attract and retain competent workers, not the amount of actual payments made in any given year or by any given vessel.

The minimum cost per ton of anchovies adopted above (i.e., \$24.58) corresponds to a crew wage which can be calculated as follows: subtract 15 percent from the weekly total costs of \$7,695 to deduct the variable trip costs; calculate total crews' share as fifty-eight percent of the net after trip costs (.58 x 6540.4 = 3793); distribute this share among twelve crew members to compute the weekly manshare, \$316. This weekly wage is equivalent to \$15,168 for a 48-week working year. This appears to be a reasonable value for labor costs. The minimum cost figure, therefore, covers the labor costs as well as the operating costs (such as fuel, netting, salt) and the owners costs (insurance, parts and maintenance, nets, taxes). It is not clear, however, that capital costs of fixed investments in vessels would be adequately covered.

Capital costs are difficult to estimate for the diverse collection of vessels operating in the anchovy fishery, Many of the vessels are of such an age that depreciation and interest charges recorded in financial statements cannot be clearly related to the value of the vessels. Many of the vessels, furthermore, are wooden-hulled vessels which would not be replicated if new vessels were to be built. It is reasonable to assume that the investment capital sunk into these vessels has been amortized long ago and that repair and maintenance expenses charged as current expenses will cover the costs of maintaining the vessels into the indefinite future. The capital costs per se arise only as a factor in decisions to build new vessels. According to Combs (p. 27), the cost of a new 58-foot purse seiner would be about \$425,000. The existing level of fishing capacity will be assumed to involve no capital cost, while additions to capacity will be equal to \$425,000 for each additional vessel capable of landing 7,500 tons of anchovy during a 32-week season. In evaluating the harvest policies for anchovy reduction, it will be assumed that no additional capital investment in vessels will be necessary so long as the annual harvest does not exceed the historical maximum seasonal catch of 141 thousand tons.

The cost of processing raw anchovies to produce meal, oil and solubles is reported by Combs (p. 49) to be \$150 per ton of meal exclusive of raw fish cost. Actually, the \$150 represents the cost of not only 1 ton of meal but also 422.4 pounds of oil and 1,232 pounds of fish solubles. This bundle of outputs has a total cost which depends upon the exvessel price of fish. At \$30/ton exvessel, the raw fish price contributes \$165 to the cost of meal oils and solubles per ton of meal. When exvessel price is \$50/ton the fish cost of the bundle of outputs rises to \$275. It is quite clear that the apparent cost of the processed product depends crucially upon the exvessel pricing agreements. Currently, the exvessel price is based upon the protein price reported weekly in the Department of Agriculture's Feed Market News (Los Angeles, California). The formula is

$$p_x = \$25 + (P_{prot} - 3) \times 7.5,$$

where p_x stands for exvessel price, and p_{prot} is the published price per unit protein from the fish meal. When price of protein is greater than \$3.00, the exvessel price is above \$25. It is not clear, however, that the fishing costs are directly affected by the protein market prices. The pricing formula can be viewed as a negotiated agreement for sharing the profits earned by the sale of fish meal.

Similarly, the amount of money paid to crew members by vessel operators is based on a sharing of operating revenue minus operating costs. To a large extent, therefore, the apparent raw fish costs to processors and the apparent labor costs on fishing vessels contain shares of profits. Windfall profits earned through market price movements, in other words, are translated back to exvessel fish prices and to crew payments where they appear as costs. An economic analysis of the harvest policies, however, should discriminate between real costs and profits distributed to various sectors of the fishery. For this reason, the convention adopted here is that fishing costs (estimated at \$24.58 per short ton) and the processing costs (\$150 per ton of meal) will be deducted from sales revenue to compute profits. The resulting figure will not correspond to reported profits of the processors, but it will be a good indicator of the total net earnings above real costs received by processors, crew members, and boat owners as a whole.

Theoretical Framework for Economic Evaluation of Anchovy Harvests

Statistical demand functions provide a practical means of assessing the value of annual production. Two sorts of economic values can be derived, the first being the market value (that is, sales revenue received by the processors on the wholesale market), and the second being total value to the consumers. The total value is composed of the sales revenue and the "consumer's surplus," the amount that the product users would be willing to pay for the quantity being used over and above the amount actually being paid. These two values are easily depicted in the diagram of a typical linear demand curve in Figure 3. For any quantity, such as Q_1, there will be a price, P_1, consistent with the market demand curve. The product $P_1 x Q_1$ equals the sales revenue achieved by the production of Q_1. Graphically, this quantity is represented by the cross-hatched area enclosed by the rectangle OP_1aQ_1.

The market value is important to the economic evaluation of the harvest because it is this value which must cover costs of production if the processors are to continue to supply the quantity being produced. In normal business decisions, therefore, the sales revenue is a key consideration. It has long been recognized that decisions seeking to maximize the public welfare must consider the additional non-pecuniary value (i.e., consumer's surplus) received by consumers. A common device used in applied welfare economics is the measure of consumer's surplus equal to the area below the demand curve but above the price line. In Figure 3, this area is represented by the speckled area $P_1\alpha a$ Thus the total value which is pertinent to public policy decisions is represented by the polygon $O\alpha aQ_1$ in Figure 3.

If there were no other considerations, such as cost of production, conservation, or enhancement of the environment, the public would be most benefited by a rate of production equal to Q_m which is the maximum amount which could be demanded. The quantity Q_m would have to be distributed as a free good, that is, at a price of zero. Given that there are costs of production which represent the value of economic inputs (labor, capital, energy and managerial expertise) used up in the production process, the appropriate economic value for public decisions is the total value net of production costs.

The foregoing narrative and graphical analysis is easily expressed in the following algebraic formulas. The demand curve (in inverted form) is

$$p = \alpha + \beta q, \tag{1}$$

where α is the intercept (i.e., the highest price which would be paid even as the quantity available approaches zero); and β is the slope (a negative number). The sales revenue is:

$$R = p \cdot q = q\ (\alpha + \beta q). \tag{2}$$

The total value is

$$T = q\ (\alpha + \tfrac{1}{2}\beta q). \tag{3}$$

The annual costs of production will generally have two components, one representing the fixed cost of maintaining the plant and equipment installed for use in the production of the commodity, and a second representing the variable costs of production which are positively related to the amount produced in any given year. The capacity for harvesting and processing anchovy into meal, oil and solubles, for instance, would be directly related to the cost of maintaining installed processing equipment and vessels dedicated to harvesting anchovies. This cost is fixed in the sense that the original investment of funds and subsequent costs associated with the tying-up of funds in the equipment will be incurred regardless of the level of harvests allowed once the investment funds are committed.

The variable costs encompass plant operating costs and vessel operating costs incurred in the harvesting and processing. If the variable costs are proportional to the level of harvest, then the total costs can be expressed as

$$C = c_1 \cdot q_{max} + c_2 \cdot q, \qquad (4)$$

where c_1 is the cost per unit capacity,
q_{max} is the capacity for production,
c_2 is the variable cost per unit production,
q is the rate of production, and
$q \leq q_{max}$.

In the absence of issues regarding the maintenance of a sufficient biomass for future biological productivity or predator fish availability, the economic criteria for annual production would be to maximize

$$V(q) = T\text{-}C = q(\alpha + \tfrac{1}{2}\beta q) - c_1\, q_{max} - c_2\, q, \qquad (5)$$

where the term, $V(q)$, represents net economic value.

One additional complication must be introduced into this simple economic model. The cost of harvesting and processing fish (i.e., c_2q) will not be simply proportional to quantity produced. Experience and theoretical considerations strongly suggest that larger annual harvests result in smaller average fish biomass levels and that these smaller biomass levels have an effect upon the costs of harvests. A general algebraic expression for the non-proportional relationship between cost per unit harvest and biomass is

$$c_2 = bB^{\gamma} \qquad (6)$$

where the values of the parameters b and γ determine the specific shape of the operating cost function. The exponent γ will be a negative number. The annual net economic value is

$$V(q,B) = q\,(\alpha + \tfrac{1}{2}\beta q) - c_1\, q_{max} - bB^{\gamma}q. \qquad (7)$$

This expression is pertinent to the evaluation of an annual harvest for a given level of capacity. A more comprehensive economic criterion for production must account for the stochastic variability of harvests and the whole time stream of economic values accruing over the life of the capital investments.

So far as the stochastic variability is concerned, a simple device for valuing the array of possible harvest levels is the mathematical expectation of the annual economic value. Given a set of possible harvest levels (q_i, i=1, ..., n) and the corresponding relative frequencies (f_i, i=1, ..., n) the expected value is computed by the following formula:

$$E\,[V(q)] = \sum_{i=1}^{n} f_i\, V(q_i). \tag{8}$$

The standard technique for evaluating a time stream of annual economic values is to consolidate the sequence of annual values into a "present discounted value" by the following formula:

$$PV = \sum_{t=1}^{N} \left(\frac{1}{1+d}\right)^t \cdot E[V(q)]_t \tag{9}$$

where t indexes the years, N is the number of consecutive years to be considered in the time series (called the "time horizon" or "planning period") and the expression $\left(\frac{1}{1+d}\right)$ represents the present value of a unit of value to be received 1 year hence with an annual discount factor of d.

Formula (9) is used to evaluate any given harvest policy. As explained in Appendix II, the natural variability of the population of anchovies gives rise to a flexible management quota system allowing annual adjustment of quotas to compensate for uncontrolled variations in biomass. Inherent in any of the suggested quota policies is a conservation motive which protects the fish stock from gross depletion and seeks a high annual average harvest. For any such policy there is a long-run, or stationary, probability distribution associated with the biomass and quotas. These probabilities are inserted into equation (8) in place of the relative frequencies f_i. The annual catches are assigned annual net economic values by equation (7). Thus E[V(q)] represents the expected annual net economic yield for a given policy.

If the stochastic process representing the biological variability results in a stationary probability distribution, as we have assumed, each year's expected value is the same as every other's. This means that the expected value expression in equation (9) can be brought outside of the summation operation, and the whole present value expression becomes:

$$PV = E[V(q)]\ [1 - (\frac{1}{1+d})^N]\ /\ [1 - (\frac{1}{1+d})] - V(q)$$

using the formula for the sum of the first N terms of a geometric series. Further simplification yields

$$PV = [E\ [V(q)]/d] \cdot [1 - (\frac{1}{1+d})^{N-1}] \tag{10}$$

Because the discount factor is a positive fraction, the term $(\frac{1}{1+d})^{N-1}$ will be small for large N, and will approach zero as N gets arbitrarily large. Also, for a given time horizon, the term will have a smaller value for larger discount rates. From a business investment standpoint, the appropriate values for N and d would be the expected life of the capital equipment used in harvesting and manufacturing operations, and the rate of return which would be earned by the investment of funds in other lines of commerce, respectively. For instance, when d=.15 and N=30; $(\frac{1}{1+d})^{N-1} = .0174$. Thus the present value is closely approximated by E[V(q)]/d, when the investment is long-lived and/or the discount rate is high.

The present value of the series of annual harvests represents the economic value of an income stream which can be achieved only after the commitment of investment funds. A more complete economic evaluation is, therefore, the present value minus the capital value of the investments. The resulting value will be called net present value "(NPV)," and has the following algebraic expression:

$$NPV = [E[V(q)]/d] \cdot [1 - (\frac{1}{1+d})^{N-1}] - I(q_{max.}) \qquad (11)$$

where $I(q_{max})$ represents the investment costs as a function of the amount of capital equipment needed to harvest q_{max}.

None of the expressions discussed here have included any consideration of the stock of fish, the conservation of the fish stock or the value of maintaining the biomass per se. The choice among various suggested harvest policies is presumed to depend upon the economic value as derived here, the social impact of the harvest schemes, the effect of harvests upon biomass and predator fish, and other factors. Thus the NPV is viewed as one important factor to consider in a broad assessment of harvest policies.

In addition to evaluating proposed harvest policies, it is possible to find the policy which maximizes the net present value of the reduction fishery. As noted in the main text of the Anchovy Plan, the alternative harvest policies represent various degrees of protection to the resource, and each policy results in an average level of biomass being maintained. Assuming that the level of biomass is associated with the value of anchovies as forage, NPV and average biomass constitute the two primary criteria for evaluating alternative harvest policies. Although the lack of adequate data and knowledge required to quantitatively value the biomass prevents an explicit optimization with respect to both criteria, the cost of adopting a policy which is more protective of the anchovy population can be assessed by comparing the economic values of the alternative policies with the maximum economic value which could reasonably be expected from the reduction fishery.

A harvest policy which maximizes the net present value of the reduction fishery can be computed by an operations research technique known as "dynamic programming" (see Hillier and Lieberman (1967) pp. 239-264). To use the dynamic programming method it is helpful to view the decision-making framework as a sequence of annual harvest decisions, each of which determines the amount of net economic value that will be produced in the succeeding year and which results in a new level of biomass at the end of the year. Because the level of biomass represents the state of the biological system to which the harvesting decision must conform, it is called the "state" variable. Similarly, because the annual quota is the variable over which the decision-makers have control it is the "decision variable." Once the state and the decisions are known the economic return is computed from the return function, V(q,B). Schematically, the process can be pictured as follows:

Initial State	Decision and Return	Ending State
B_t ⟶	q_t ⟶	B_{t+1}
	V(q,B)	

The ending state becomes the initial state for the next decision, and so on for an endless sequence of periodic decisions.

The dynamic programming algorithm devised by Bellman (1957) provides a method for computing the sequence of decisions maximizing the net discounted value of the fishery over a long sequence of years. Fortunately, the time discount factor causes decisions and resulting economic returns in the distant future to have little or no impact on net present value. Thus the length of the sequence of decisions which needs to be considered can be represented as some large, but finite, number of years, such as fifty years. As a practical matter the decisions (i.e., quotas) corresponding to all possible states (i.e. biomass levels) during the first 30 or so years of the dynamic programming model will be identical to the decisions which would be optimal in an infinitely long sequence of years.

The optimizing problem can be expressed mathematically as follows:

$$\text{Maximize} \left[\sum_{t=o}^{N} V(q_t, B_t)\left(\frac{1}{1+d}\right)^t - I(q_{max}) \right] \qquad (12)$$

where $V(q_t, B_t) = q_t\ (\alpha + 1/2\ \beta q_t) - c_1 q_{max} - bqB^{\gamma}{}_t$;

$$B_t = B_{t-1}\, e^{-(F+M-G)} + \left(\left(\frac{1}{B\infty} + \left(\frac{1}{B_{t-1}} - \frac{1}{B\infty} \right) e^{-r} \right)^{-1} - B_{t-1} e^{-(M-G)} \right) e^{-\Phi F\tau}$$

and catch, q_t, is determined by application of equation (11) of Appendix II. For the given values of α, β, c_1, b and γ from the analysis of demand and production costs, and for the estimated values of M, G, $B\infty$, r, Φ and τ from Appendix II, the maximization of (12) can be accomplished for any initial biomass.

Numerical values of the parameters in this mathematical model are derived from earlier sections of this Appendix and from Appendix II as follows:

(1) The annual total value of the fish meal produced from anchovy in California is a function of anchovy landings from the regression equation,

$$P_{CALFM} = 1.082 - .0048 \text{ CFMP} , \tag{13}$$

where, as explained above, P_{CALFM} is the price of California fish meal per unit protein relative to the average U.S. price, and CFMP is the annual production of tuna and anchovy meal in California in protein-equivalent units. Because the California production of meal does not appreciably affect the U.S. average price, an expression relating California price to California production is determined by multiplying equation (13) by the average U.S. price during the period 1971-1976 ($5.66). Also, the average production of tuna meal (22 thousand tons) can be netted out of the independent variable to leave the following expression for average California anchovy price per unit protein as a function of anchovy meal in protein-equivalent units;

$$P_{CALFM} = 5.525 - .02714 \text{ ANCHP} \tag{14}$$

where P_{CALFM} now represents California fish meal price per unit protein in dollars and ANCHP is thousands of tons of anchovy fish meal protein. The entire equation is converted to the more natural units of value per unit harvest as a function of anchovy landings.

$$v = 65.295 - 3.7906 \times 10^{-5} q, \tag{15}$$

where v is sales value per ton of harvest (equals $P_{CALFM} \times (65/5.5)$, assuming anchovy meal is 65 percent protein and that 5.5 tons of anchovies yield one ton of meal), and q is the annual harvest of anchovies in tons (equals ANCHP x .65/[5.5·1000]).

The sales revenue and total value to consumers can, using equations (2) and (3), be expressed as follows:

$$R = q\,(65.295 - 3.7906 \times 10^{-5} q),$$

$$T = q\,(65.295 - 1.8953 \times 10^{-5} q).$$

Recognizing that the sales value accruing from a ton of processed anchovy includes the value of fish oil and solubles as well as the value of the meal, we should add the value of the oil and solubles produced per ton of anchovies processed into the equation. The average price for anchovy oil during 1970-1976 converted to 1977 prices is 12.87¢ per pound. Assuming that the average production of oil per ton of anchovies processed will continue to be 76.8 pounds, the average value of oil produced per ton of anchovies landed will be $9.88. Similarly, the average value of fish solubles during the period 1970-1976 is $105. per ton in 1977 dollars (see Table 7).

Using the rule-of-thumb that the volume of fish solubles produced equals 11.2 percent of the weight of anchovies processed, the fish solubles can be expected to contribute $11.76 per ton of anchovies harvested.

The total value of the anchovy reduction products is finally expressed as a quadratic function of annual landings:

$$T = q(86.94 - 1.8953 \times 10^{-5}q) \qquad (16)$$

(2) According to Earl Combs (1977) the minimum cost per ton of landings in 1977 is $24.58. The estimate is presumably reflective of the fishing conditions (biomass level, catch per day of fishing, and weather) during the fishing season in 1975. As noted above, however, the catch of fish per unit of fishing time is generally dependent upon the size of the fish stock. This fact is often expressed in fish population models as a declining catch per effort as catch increases. In the anchovy fishery it has not been demonstrated that there is a proportional relationship between catch per day of fishing and anchovy biomass. Nevertheless, an analysis of a very similar fishery in California, the sardine fishery, indicates that there was a nonlinear relationship between catch per unit of fishing time ("effort") and fish abundance (see MacCall, 1976). According to MacCall, the catch per unit effort (CPUE) was related to sardine abundance approximately as follows:

$$\mathrm{CPUE} = aB^{0.4}.$$

If the cost of fishing is proportional to the amount of time spent fishing, then cost per ton of fish would be inversely related to the catch per unit effort. Thus a general function for cost per ton (CPT) would be

$$\mathrm{CPT} = \frac{1}{a}\ B^{-0.4}.$$

There is no reason to believe that the cost per ton of anchovies would be related to the anchovy biomass in precisely this fashion. Nevertheless, it is clearly unreasonable to assume that cost per ton of anchovies would remain constant at $24.58 regardless of the size and density of the fish stock. If the biomass were to fall from the estimated 3.6 million tons in 1975 to, say, less than 1.0 million tons, the increasing scarcity of anchovy schools would undoubtedly result in a lower average catch per day fishing and a higher cost per ton of fish landed.

If the equation relating CPUE and fish biomass for the sardine fishery is adopted as a reasonable functional form for the corresponding relationship in the anchovy fishery, the postulated relationship between cost per ton and anchovy biomass can be specified. Because the cost per ton of fish in 1975 corresponds to a biomass of approximately 3.6 million tons, the value of the parameter $\frac{1}{a}$ is 10315. The resulting cost per ton relationship is

$$CPT = 10315\ B^{-0.4}. \qquad (17)$$

Also, the CPUE relationship to biomass is

$$CPUE = .186\ B^{0.4}. \qquad (18)$$

Equations (17) and (18) are illustrated in Figure 4. The cost per ton remains in a relatively narrow range about $26 when biomass is in the range of 2.0 to 5.0 million tons.

(3) The cost of processing the harvest amounts to $150 per ton of meal produced, which converts to $27.27 per ton of anchovy landed. Subtracting this processing cost and the fishing cost from the total value equation (16), yields

$$T = V(q,B) = (59.67 - 1.8953 \times 10^{-5} q)q - 10315\ B^{-0.4} q \qquad (19)$$

(4) Capital costs associated with investments in processing machinery and vessels were introduced in the earlier section on Production Costs. Each additional vessel costing $425,000 should be capable of harvesting at least 7500 tons of anchovy during a typical 32-week season. If the season is extended to June 30, the vessel might catch 8900 tons of anchovies. And if the anchovy reduction fishery were to operate year-round, the $425,000 vessel would probably be able to harvest around 12,200 tons annually. The number of vessels needed to take a given quota and, therefore, the capital cost incurred in building a fleet are related to the length of the allowed fishing season.

A reasonable estimate of fishing fleet capital costs is made by assuming that a new vessel will be needed for each 10,000 tons of harvest capacity exceeding the existing estimated capacity of 247,000 tons (see section 5.0). The annualized capital cost per vessel, assuming a normal 15 percent return on investment, would be .15 x \$425,000 = \$63,750/year. If the vessel catches 10,000 tons of anchovies per year, then the average vessel capital cost per ton of catch capacity is \$6.38.

Each processing facility capable of reducing 108 thousand tons of anchovies per year has a replacement cost of about \$1.5 million. The annualized cost, at a 15 percent return, is \$225,000/year. Assuming the plant processes 108 thousand tons of anchovy per year, the average processor capital cost per ton of processing capacity is \$2.083. Algebraically, the total capital cost per ton of fishing and processing capacity is expressed as

$$C = 8.463\, q_{max} \tag{20}$$

Discussion of Results

The policy which maximizes the net discounted value of the fishery was determined by a dynamic programming algorithm for the following four cases:

I. No economic costs or values are considered, so that $V(q,B) = q$;

II. The entire fishery harvest is assumed to be caught by the domestic fishery, so that equation (19),

$$V(q,B) = (59.67 - 1.8953 \times 10^{-5}\, q)q - 10315\, q\, B^{-0.4}$$

is the annual net economic value for the fishery;

III. The U.S. harvest is 70 percent of the total harvest, so that the quantity variable, q, in equation (19) is 70 percent of the annual harvest;

IV. The U.S. harvest is 50 percent of the total harvest, so that the quantity variable, q, in equation (19) is 50 percent of the annual total harvest.

Case I corresponds to the maximum physical yield objective often esposed by fisheries biologists, and is included here for comparison to Cases II-IV. The maximum present values for Cases II-IV are achieved when the annual U.S. catch is related to the initial biomass in the following manner:

$$\text{II. Catch} = -345477 + .45347\ B - 4.666 \times 10^{-8}\ B^2.$$

$$\text{III. Catch} = -322892 + .37497\ B - 3.318 \times 10^{-8}\ B^2.$$

$$\text{IV. Catch} = -333399 + .3433\ B - 3.175 \times 10^{-8}\ B^2.$$

These catch policies are illustrated in Figure 5. Because the equations are quadratic approximations the prescribed annual U.S. catch will reach a maximum at some large biomass. For Case II the maximum catch is 756,297 tons at a biomass of 4,859,301 tons; for Case III the maximum catch is 736,271 tons at a biomass of 5,649,336 tons; and for Case IV the maximum catch is 594,592 tons at a biomass of 5,406,299. These maximum catches would never actually occur, of course, so long as the management policy maintains the population within a small range about the long-run average optimum values. For each of the four Cases the equilibrium optimum annual catch, biomass, and economic return are as shown in Table 8.

These results are from the dynamic programming model without stochastic variation in the biomass. The full evaluation of any proposed harvest policy, including the ones calculated to yield maximum economic value, should be accomplished within the context of a stochastic model such as the one developed for the anchovy biomass model in Appendix II. Essentially, this stochastic (Markov) model computes the stationary probability distribution of biomass and annual catch corresponding to any given harvest policy. Given this probability distribution, the expected economic value of the harvests under the policy are computed by equation (8). The net present value can then be computed by application of equations (11) and (20). The same evaluation technique is just as applicable to the proposed alternative harvest policies from the main text of the anchovy plan as it is to the maximum economic value policy determined by the dynamic programming model.

One important issue which becomes more complex in the stochastic context is that of optimal level of capital stock (ships and processing plants). In the deterministic context of the dynamic program, the optimal stock of capital is easily identified with the equilibrium level of harvest. However, when the biomass is assumed to be subject to random fluctuations, and the harvest policy adapts to these by varying the annual quota, the quota will occasionally be well above the average annual yield considered in the deterministic model. The economic issue is: to what extent is it justifiable to expand the stock of capital in order to take advantage of increasingly infrequent but larger potential catches? Because the probability distribution of annual quotas for any given harvest policy is computed by the stochastic model, the economic issue can be answered in terms of expected net values. The cost of increasing capacity is estimated by equation (20). The expected payoff is calculated by inserting the probability and catches from the stochastic model into equation (9). By considering, sequentially, a series of harvest policies with increasingly larger maximum allowable harvests (and correspondingly larger capital costs), the optimum level of capital stock can be estimated.

To see how this is done, consider the Option 2 harvest policy. Seven catch limits were arbitrarily imposed upon the harvest policy, and for each limit the stochastic model was used to evaluate the harvest policy with the following results:

Catch limit imposed	Total U.S. value net of operating cost (1000 dollars)	Industry earnings (1000 dollars)
100,000 tons	2,024	1,943
200,000 tons	3,566	3,271
300,000 tons	4,684	4,095
400,000 tons	5,468	4,545
600,000 tons	6,360	4,766
800,000 tons	6,737	4,529
1,000,000 tons	6,862	4,148

The term "Total U.S. Value Net of Operating Cost" represents the estimate of sales value plus consumer's surplus minus fishing and processing costs, as calculated from equation (19). The term "Industry Earnings" represents the estimated sales revenue minus fishing and processing costs.

The curves plotted in Figure 6 will assist the reader in understanding the use of the computations listed above. The Total Values lie on the curve labelled "Total U.S. Value." The Industry Earnings value lie on the curve labelled "U.S. Industry Earnings." Each of these curves represents a simple empirical "fit" to the computed points. Along the horizontal axis, the assumed maximum catch limit increases to the right. Thus the rising portion of the Total Value curve indicates that the economic value of the fishery increases with increasing capacity. As would be expected, the capacity is subject to diminishing returns.

A social optimum level of capacity is defined as that level which equates marginal value with marginal cost. The plotting of a "capital cost" curve facilitates the illustration of this point. The capital cost is related to capacity of the fishery as indicated in equation (20); that is, each ton of additional capacity costs $8.46. Because the United States is assumed, in this example, to get 70 percent of the catch, and because the economic values of concern are those for the United States, the capital cost curve has a slope equal to 70 percent of the cost per ton of capacity. The point on the Total Value curve at which the slope is equal to the slope of the capital cost line (indicated by the tangent dashed line) represents the economic optimum. As noted in Table 10, the optimum occurs at a maximum catch of 420 thousand tons.

A second capital cost line, labelled "one-half capital cost," is included because the total annualized cost represented by the original line accounts for the cost of new vessels and new processing plants and assumes that the entire construction cost must be charged to the anchovy reduction fishery. This cost represents a maximum of likely capital costs; however, the actual costs may be lower because existing plants and vessels involve lower capital costs than prospective new ones, and because some of the capital cost may be charged against fisheries for other species. It seems reasonable that at least half of the new cost of capital equipment should be charged to the anchovy fishery. Thus, the actual costs probably lie between the two curves. Based on the lower capital cost line, the optimum economic capacity would be 580 thousand tons per year. The resulting range of optimal capacity, 420-580 thousand tons, corresponds to a range of potential net economic yield, measured as Total U.S. Economic Value net of operating costs <u>and</u> capital costs. For Option 2, with a 70 percent U.S. fishery, the range of values is 3.1 to 4.5 million dollars.

Another concept illustrated in Figure 6 is that of competitive industry equilibrium. It is generally held that competitive firms will continue to invest in new capital equipment until the prospective return falls below the cost of the equipment. As illustrated in Figure 6, the competitive equilibrium occurs at the intersection of the industry earnings curve and the capital cost line. Again, with two capital cost lines there will be two equilibrium capacities. The "competitive equilibrium" capacity based upon the full capital cost line is equal to the assumed catch limit used in Tables 8.3-2 and 8.3-3 of the main text of the Plan. These assumed catch limits are used in making the estimates of catch, biomass, average gross market value, and U.S. Total Value net of operating costs in Tables 9a and 9b.

The economic contributions of the anchovy reduction fishery estimated here must be used with caution, both because the assumed economic conditions and the assumed environmental conditions could change drastically. A sudden increase or decrease in the demand for fish meal, for instance, would substantially alter the outcome of the optimum economic yield calculations. Likewise, a change in fishing or harvesting costs would have an impact on the economic values. The biological system upon which the estimated population growth depends is assumed to remain as it was during the period 1951-1975. If an episode of minimal upwelling and low recruitment were to occur (such as appeared to occur during 1946-1949) the population model would not predict well.

In conclusion, although there is a great deal of economic and biological variation and uncertainity in the real world, the mathematical model of the fish stock and harvesting/processing industry provides reasonable information about the potential value of the alternative harvest policies.

Table 1. World production of oilcake meals, 1960-1975; and FAO price indices, 1967-75.

Year	Production: Fish meal 1/	Soybean meal 2/	Other vegetable meal 2/	Total, protein equivalent 3/	FAO Price Indices: Fish meal	Vegetable oilcakes
	(1,000's short tons)				(1964-66 = 100)	
1960	2,221	19,014	16,729	17,231	-	-
1961	2,771	18,207	17,399	17,529	-	-
1962	3,118	20,166	18,082	18,907	-	-
1963	3,223	20,973	18,990	19,661	-	-
1964	3,989	21,779	19,093	20,635	-	-
1965	3,940	23,162	21,165	22,084	-	-
1966	4,471	25,236	20,911	23,242	-	-
1967	5,030	26,504	20,643	23,040	77	99
1968	5,501	27,541	20,992	25,197	76	97
1969	5,236	29,155	20,784	25,395	104	95
1970	6,041	32,067	22,548	27,999	117	104
1971	5,897	33,069	23,800	29,784	104	103
1972	4,707	36,150	25,127	29,652	141	125
1973	4,332	38,756	23,975	30,093	315	269
1974	4,872	48,527	25,377	35,737	216	186
1975	4,850	42,163	25,127	32,650	143	156

Sources: FAO, Commodity Review and Outlook, various issues.

1/ Product weight.

2/ Converted to 44% protein equivalent.

3/ 100% protein.

Table 2. Quantity of high-protein feed available in the United States (in terms of 44% protein equivalent).

Year	Oilseed meal 1/	Animal protein 2/	Grain protein 3/	Total	U.S. fish meal total supply 4/
	(1,000 tons)				
1955	8,471	3,233	897	12,601	493
1956	9,350	3,005	857	13,212	523
1957	10,116	2,838	859	13,813	467
1958	11,143	3,056	903	15,102	474
1959	10,655	3,103	972	14,730	601
1960	11,259	3,281	947	15,487	578
1961	11,687	3,421	1,052	16,160	732
1962	11,976	3,543	1,069	16,588	783
1963	11,656	3,743	1,136	16,545	894
1964	11,804	3,557	1,181	16,542	955
1965	12,689	3,557	1,238	17,504	730
1966	12,561	3,950	1,250	17,761	951
1967	12,240	4,240	1,283	17,831	1,238
1968	13,520	3,868	1,298	18,686	1,573
1969	15,310	3,444	1,321	20,075	864
1970	15,227	3,539	1,319	19,861	723
1971	15,093	3,616	1,008	19,717	805
1972	14,131	3,059	1,134	18,234	940
1973	15,799	3,012	1,202	20,013	434
1974	14,250	3,050	1,125	18,425	424
1975	17,004	3,179	1,238	21,421	543
1976	16,350	3,400	1,250	21,000	572

Sources: U.S. Dept. Agriculture, Economic Research Service, 1972. Feed Situation. FdS-244 (May).

_____. 1977. Feed Situation, FdS-265 (May).

National Marine Fisheries Service. 1977. Industrial Fishery Products, Annual Summary. Current Economic Analysis 6702 (March).

1/ Oilseed meal includes soybean, cottonseed, linseed, peanut and copra meal. During 1970-76 soybean meal accounted for 73 percent of the oilseed meal used in high-protein animal feeds.

2/ Animal proteins include tankage and meat meals, fish meal and solubles, commercial dried milk products and noncommercial milk produced. During 1970-76, tankage and meat meal accounted for 65 percent and fish meal 19 percent of the total.

3/ Grain protein includes gluten feed and meal, brewer's dried grains, and distiller's dried grains.

4/ Equals col. (7) of Table 3 divided by .44.

Table 3. United States fish meal supplies, 1955-1976 (thousands of short tons).

Year	(1) Menhaden	(2) Tuna	(3) Anchovy	(4) Other[1/]	(5) Imports	(6) Exports	(7) Total supply, protein basis[2/]
1955	190.6	23.4	-	41.5	98.0	n.a.	215.8
1956	210.6	26.3	-	48.6	90.4	n.a.	228.7
1957	172.4	25.7	-	56.5	81.2	n.a.	204.3
1958	158.1	25.3	-	55.3	100.0	n.a.	207.2
1959	223.9	25.4	-	47.5	132.9	n.a.	263.2
1960	218.4	26.5	-	36.5	131.6	n.a.	253.1
1961	247.6	21.2	-	31.7	217.8	n.a.	320.8
1962	239.7	26.6	-	34.7	252.3	n.a.	343.3
1963	184.2	27.0	-	36.8	376.3	n.a.	392.0
1964	160.3	21.1	-	43.6	439.1	n.a.	419.4
1965	176.0	25.4	-	41.1	270.6	n.a.	320.1
1966	135.0	25.3	4.5	47.3	447.8	n.a.	417.3
1967	119.1	25.5	5.6	51.3	651.5	n.a.	543.4
1968	143.2	28.8	2.8	52.2	855.3	n.a.	690.8
1969	159.5	26.9	11.4	46.4	358.4	n.a.	378.7
1970	188.6	26.7	16.2	25.6	251.1	4.7	317.0
1971	220.9	29.3	7.7	25.0	283.2	10.1	352.7
1972	193.6	43.2	11.1	26.2	392.0	10.5	411.4
1973	188.8	43.6	22.0	24.7	68.5	55.5	188.9
1974	203.9	48.2	14.1	25.4	68.3	36.7	184.4
1975	191.4	37.2	27.7	23.0	118.4	11.8	236.9
1976	212.6	40.1	21.9	24.3	140.4	33.1	249.8

Sources: National Marine Fisheries Service. 1977. Industrial Fishery Products, Market Review and Outlook. Current Economic Analysis I-29 (June).

National Marine Fisheries Service. 1977. Industrial Fishery Products, Annual Summary. Current Economic Analysis 6702 (March).

n.a. = data not available

1/ Primarily from offal, waste and scrap from groundfish, and herring.

2/ Converted to protein as follows: menhaden, exports, and other meal assumed to be 60 percent protein; anchovy and imports assumed to be 65 percent protein; tuna meal assumed to be 55 percent protein. Total supply is production plus imports minus exports.

Table 4. Annual average prices for various fish meals, soybean meal, and average price per unit protein in fish meal in the United States.

Year	Menhaden[1/]	Tuna[2/]	Domestic[3/] anchovy	Peruvian[4/] anchovy	Domestic[5/] soybean meal	Average price per unit protein in fish meal	
	(dollars per ton of meal)					Actual[6/]	Deflated[7/]
1955	136.0	144.1	-	-	56.9	2.19	4.79
1956	134.2	134.2	-	-	51.3	2.17	4.58
1957	129.7	126.6	-	134.0	47.1	2.15	4.42
1958	137.8	137.6	-	141.3	56.0	2.22	4.62
1959	128.1	129.1	-	145.4	56.5	2.15	4.36
1960	93.0	94.8	-	94.9	53.1	1.53	3.09
1961	117.3	109.9	-	110.3	63.2	1.86	3.75
1962	124.1	120.7	-	122.6	66.5	1.99	4.01
1963	125.8	117.1	-	120.9	72.5	1.94	3.95
1964	131.5	127.7	-	132.0	69.2	2.07	4.20
1965	168.5	157.8	-	154.6	71.5	2.54	5.10
1966	161.0	148.1	151.3	156.4	83.8	2.46	4.77
1967	136.5	129.6	129.5	130.2	76.5	2.05	3.94
1968	145.3	125.9	122.0	131.0	77.5	2.07	3.89
1969	174.3	146.2	152.0	157.0	74.5	2.55	4.67
1970	184.5	171.3	172.0	194.5	79.2	3.00	5.20
1971	158.0	141.1	154.8	166.1	77.9	2.57	4.32
1972	185.5	155.9	169.9	179.2	104.9	2.85	4.58
1973	478.2	396.4	402.9	451.7	238.4	7.44	10.69
1974	276.1	270.6	297.9	287.3	140.9	4.57	5.49
1975	239.1	227.4	236.8	249.7	124.1	3.90	4.28
1976	346.4	273.2	272.8	341.6	162.6	5.42	5.67

Sources: National Marine Fisheries Service. 1977. Industrial Fishery Products, Market Review and Outlook. Current Economics Analysis, I-29 (June).

California Department of Fish and Game. California Marine Fish Landings, Various issues.

1/ 60 percent protein. Average price quoted by brokers at New York City, weighted by monthly production of menhaden meal.

2/ 60 percent protein. Average price quoted by brokers at Los Angeles, weighted by monthly production.

3/ 65 percent protein. Annual value divided by annual production.

4/ 65 percent protein. Average f.o.b. East Coast ports price, weighted by monthly imports.

5/ 44 percent protein. Simple average price at Decatur, Illinois.

6/ For each meal, price per unit protein equals price per ton divided by percent protein. Average price computed by weighting the price per unit protein for each meal by the proportion of U.S. fish meal protein supplied by that meal.

7/ Deflated by Wholesale Price Index, all commodities (Jan. 1977 = 100).

Table 5. World production of fish oil, world exports and export prices of fish oil and vegetable oil, 1958-1975.

Year	Production: (million lbs.) Fish oil[1/]	World exports: (million lbs.) Fish Oil	Vegetable Oil[2/]	Export prices: (cents/lb.) Fish Oil	Vegetable Oil[3/]
1958	639	304	3,797	8.2	5.7
1959	800	452	4,598	10.8	5.5
1960	862	553	4,779	6.8	5.5
1961	1,190	664	4,082	6.1	6.1
1962	1,351	807	4,840	4.7	5.2
1963	1,219	930	4,984	5.1	5.2
1964	1,563	844	5,490	7.5	5.5
1965	1,598	983	5,611	8.4	5.9
1966	1,823	1,008	5,870	7.9	5.8
1967	2,315	1,360	4,889	5.5	5.4
1968	2,271	1,429	5,196	4.5	4.9
1969	1,900	1,179	5,640	4.5	5.1
1970	2,138	1,089	6,973	8.7	6.5
1971	2,414	1,254	7,966	9.0	6.5
1972	1,911	1,444	8,343	6.8	6.0
1973	1,689	968	8,531	12.0	10.9
1974	2,116	990	9,672	21.3	18.2
1975	2,131	1,151	9,954	14.5	13.7

[1/] Fish body oils and similar products, not including fish liver oils.

[2/] Includes soybean oil, castor oil, cottonseed oil, groundnut oil, linseed oil and palm oil.

[3/] Average weighted export prices of soybean oil, castor oil, cottonseed oil, groundnut oil and palm oil.

Sources: FAO Yearbook of Fishery Statistics, various issues.
FAO Trade Yearbook, various issues.
FAO Production Yearbook, various issues.

Table 6. U.S. production and prices of fish oil[1/] and vegetable oil[2/], 1958-1976.

Year	Production: (million lbs.) Total Fish Oil	Anchovy Fish Oil	Vegetable Oil	Prices: (cents/lb.) Menhaden[3/] Fish Oil	Anchovy[4/] Fish Oil	Vegetable[5/] Oil
1958	161.6	-	6,217	8.0	-	10.3
1959	183.2	-	6,664	7.6	-	9.1
1960	205.6	-	6,616	6.2	-	11.5
1961	254.6	-	7,060	6.1	-	10.6
1962	247.5	-	7,443	4.2	-	9.5
1963	183.7	-	7,195	6.7	-	9.1
1964	177.0	-	7,572	8.8	-	11.4
1965	192.8	-	8,145	9.3	-	12.1
1966	162.7	0.7	7,752	9.4	7.3	10.7
1967	119.9	1.0	7,411	6.4	3.9	9.3
1968	171.7	0.9	8,257	4.7	3.6	9.1
1969	168.0	4.9	9,476	5.8	4.3	11.3
1970	206.1	6.2	9,841	10.2	7.1	12.9
1971	265.0	3.2	9,595	8.8	5.5	11.4
1972	188.4	4.4	9,429	7.2	5.4	15.8
1973	224.6	10.5	10,890	11.6	11.2	31.3
1974	238.0	5.6	8,985	25.4	14.9	31.6
1975	245.6	12.9	10,846	16.0	12.0	19.1
1976	204.4	5.2	10,190	17.0	13.1	21.4

[1/] Excludes whale and sperm oil

[2/] Includes U.S. soybean oil, cottonseed oil and linseed oil.

[3/] Crude oil in tank cars, average weighted price, New York City.

[4/] Average weighted price. Anchovy utilization prior to 1966 was negligible.

[5/] Average weighted price of U.S. soybean oil, cottonseed oil and linseed oil.

Sources: National Marine Fisheries Service. 1977. Industrial Fishery Products, Market Review and Outlook. Current Economic Analysis I-29, June.

U.S. Dept. of Agriculture, Economic Research Service, Fats and Oils Situation, various issues.

National Marine Fisheries Service, Statistical Digests, Fishery Statistics of the United States, various published and unpublished issues.

Table 7. U.S. Fish soluble production and prices, 1958-1976.

Year	Production: (1000 short tons) Total	Menhaden	Anchovy[1/]	Prices: ($/short ton) Total[2/]	Deflated[3/]
1958	130.2	72.5	-	97.5	195.8
1959	165.4	108.1	-	67.6	135.5
1960	98.9	65.8	-	37.7	75.6
1961	112.2	73.3	-	47.2	95.0
1962	124.6	85.2	-	55.1	110.4
1963	107.4	74.8	-	63.1	127.0
1964	93.3	68.7	-	62.0	124.5
1965	94.8	73.2	-	58.3	114.8
1966	83.4	60.8	3.1	70.7	134.7
1967	74.7	51.8	3.6	63.2	120.2
1968	71.8	53.2	1.5	52.9	98.1
1969	81.7	63.3	7.0	49.6	88.6
1970	95.0	71.9	10.4	51.9	89.3
1971	111.2	91.5	4.9	47.3	79.0
1972	134.4	104.1	7.5	43.4	69.2
1973	137.4	104.4	14.6	134.9	190.3
1974	137.3	102.9	9.1	89.7	106.4
1975	127.8	83.6	17.3	66.4	72.2
1976	132.9	95.3	12.1	123.8	128.6

[1/] Fish solubles are not reported for anchovies specifically. These figures are based upon the rule-of-thumb that the yield of solubles equals 11.2 percent of raw anchovy input.

[2/] Total average weighted fish soluble price. Separate prices for anchovy fish solubles are not reported.

[3/] Deflated according to wholesale price index for all commodities, January 1977 = 100.

Source: National Marine Fisheries Service. 1977. Industrial Fishery Products, Market Review and Outlook, Current Economic Analysis I-29.

Table 8. Results of the Four Dynamic Programming Models for Anchovy Fishery Harvests

Equilibrium Characteristics	Case I[1/]	Case II[2/]	Case III[3/]	Case IV[4/]
	(thousand tons)			
U.S. Annual Catch	484	458	327	237
Average Biomass at Start of Fishing Year	1,819	2,253	2,167	2,084
	(thousand dollars)			
Maximum Economic Yield with Limited Access	---	8,951	7,003	5,335
U.S. Total Value Net of Operating Costs	---	5,075	5,066	4,332

1/ Biological criteria equivalent to MSY.

2/ Net economic value criteria with 100% domestic fishery.

3/ " " " " with 70% domestic fishery.

4/ " " " " with 50% domestic fishery.

5/ Sales value plus consumer's surplus minus operating costs associated with harvesting and processing (Equation 19).

6/ Sales value plus consumer's surplus minus operating costs minus capital costs associated with U.S. annual catch.

Table 9a. U.S. economic values for various harvest policies, estimated from Markov model and assuming a 70% U.S. share of the harvest.

	Harvest Policy Evaluated					
	Option[1] #1	Option[2] #2	Option[3] #3	Option[4] #4	Option[5] #5	Option[6] #6
	(thousand tons)					
Average Annual Catch	290	371	355	284	384	378
Average Biomass	2,870	2,550	2,570	3,000	2,170	2,160
Average Gross Market Value of Reduction Products, U.S.[7]	$16.1	$20.1	$19.1	$15.8	$20.7	$20.4
U.S. Total Value Net of Operating Costs[8]	$ 5.8	$ 6.7	$ 6.5	$ 5.8	$ 6.4	$ 6.2
U.S. Potential Net Economic Yield with Limited Access Program[9]	$ 3.1	$ 3.1 - 4.5	$ 3.0 - 4.4	$ 2.8 - 4.0	$ 3.0 - 4.3	$ 3.0 - 4.3

Footnotes: see Table 9b.

Table 9b. U.S. economic values for various harvest policies, estimated from Markov model and assuming a 50% U.S. share of the harvest.

	Harvest Policy Evaluated					
	Option[1] #1	Option[2] #2	Option[3] #3	Option[4] #4	Option[5] #5	Option[6] #6
	(thousand tons)					
Average Annual Catch	291	396	370	287	403	401
Average Biomass	2,870	2,450	2,530	2,990	2,090	2,040
Average Gross Market Value of Reduction Products, U.S.[7]	\$11.8	\$15.7	\$14.8	\$11.7	\$16.0	\$15.9
U.S. Total Value Net of Operating Costs[8]	\$ 4.34	\$ 5.4	\$ 5.2	\$ 4.4	\$ 5.1	\$ 5.0
U.S. Potential Net Economic Yield with Limited Access Program[9]	\$ 2.5	\$ 2.4 - 3.7	\$ 2.4 - 3.5	\$ 2.1 - 3.0	\$ 2.4 - 3.5	\$ 2.3 - 3.4

Footnotes:

1 Catch equals 33 percent of biomass in excess of 1 million tons with a maximum catch of 450 thousand tons.

2 Same as Option #1, but with an assumed maximum annual catch of 970 thousand tons.

3 Catch equals 20 percent of biomass in excess of .5 million tons, with an assumed maximum annual catch of 970 thousand tons.

4 Catch equals 10 percent of biomass if biomass is greater than 1.0 million tons and assuming the maximum annual catch is 960 thousand tons.

5 Catch equals 25 percent of biomass if biomass is above 1.0 million tons, and assuming that the maximum annual catch is 910 thousand tons.

6 Catch is 33.3 percent of the biomass in excess of 0.5 million tons with an assumed maximum annual catch of 900 thousand tons.

7 Estimated market value based upon market demand equation (15) and assuming \$21.64 worth of oil and solubles result from each ton landed.

8 Market value plus consumer's surplus minus operating costs by equation (19).

9 Equals annual average total value minus operating costs and minus estimated investment cost for optimal capacity.

Table 10. Maximum Annual Catch and Maximum Economic Value Assuming an Effective Limited Access Program[1].

	Option 1	2	3	4	5	6
Maximum Annual Catches from Fishery:						
with 50% U.S. share	450	470-690	440-630	360-510	440-570	430-620
with 70% U.S. share	420-450	420-580	400-560	345-475	380-550	390-540
U.S. Potential Net Economic Yield:						
with 50% U.S. share	2.5	2.4-3.7	2.4-3.5	2.1-3.0	2.4-3.5	2.3-3.4
with 70% U.S. share	3.1	3.1-4.5	3.0-4.4	2.8-4.0	3.0-4.3	4.2-4.3

[1] See Figure 6. Range of values depends on range of capital cost figures.

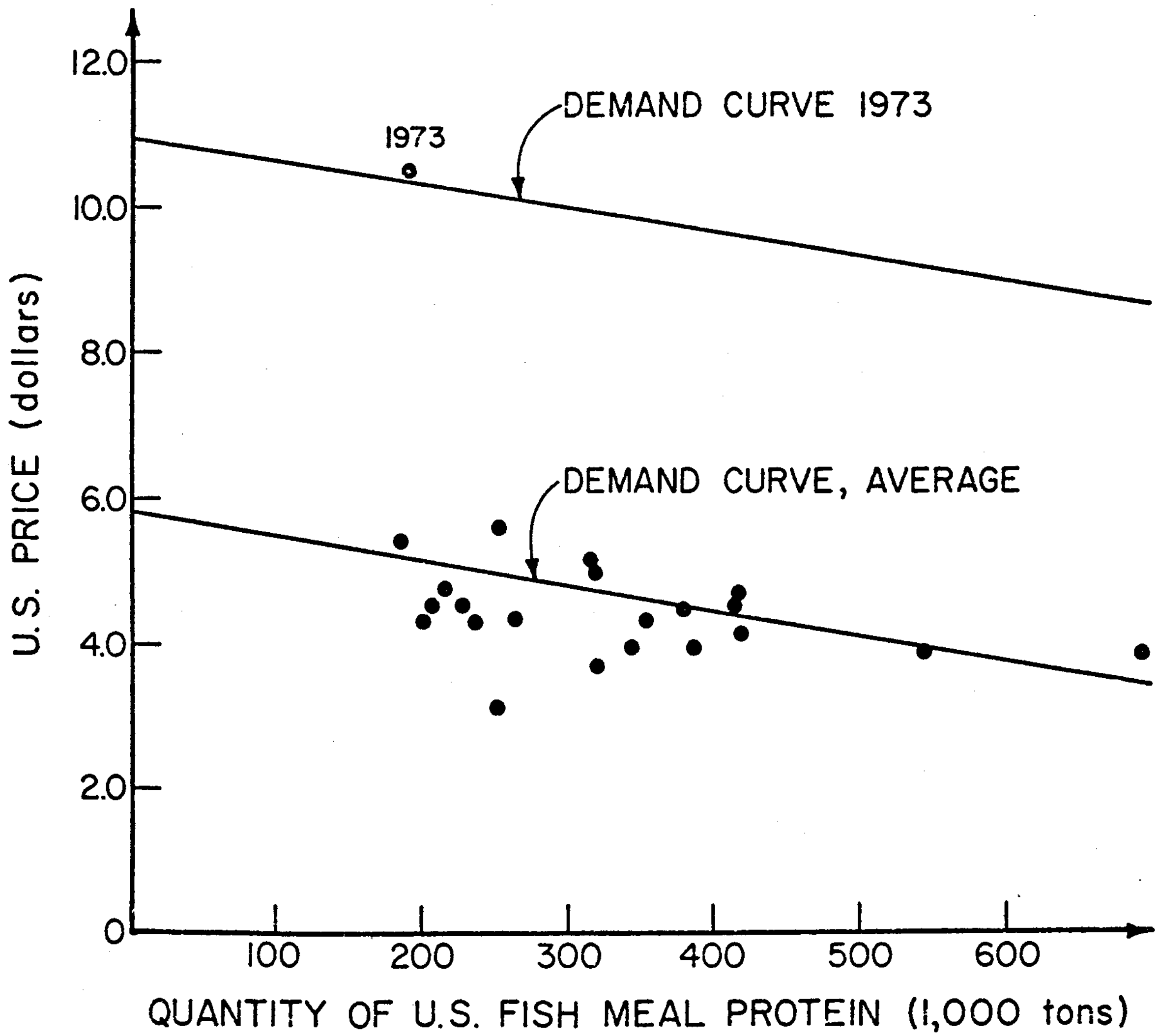

Figure 1. Plot and regression of U.S. fish meal prices and apparent consumption in protein equivalent units, 1955-1976.

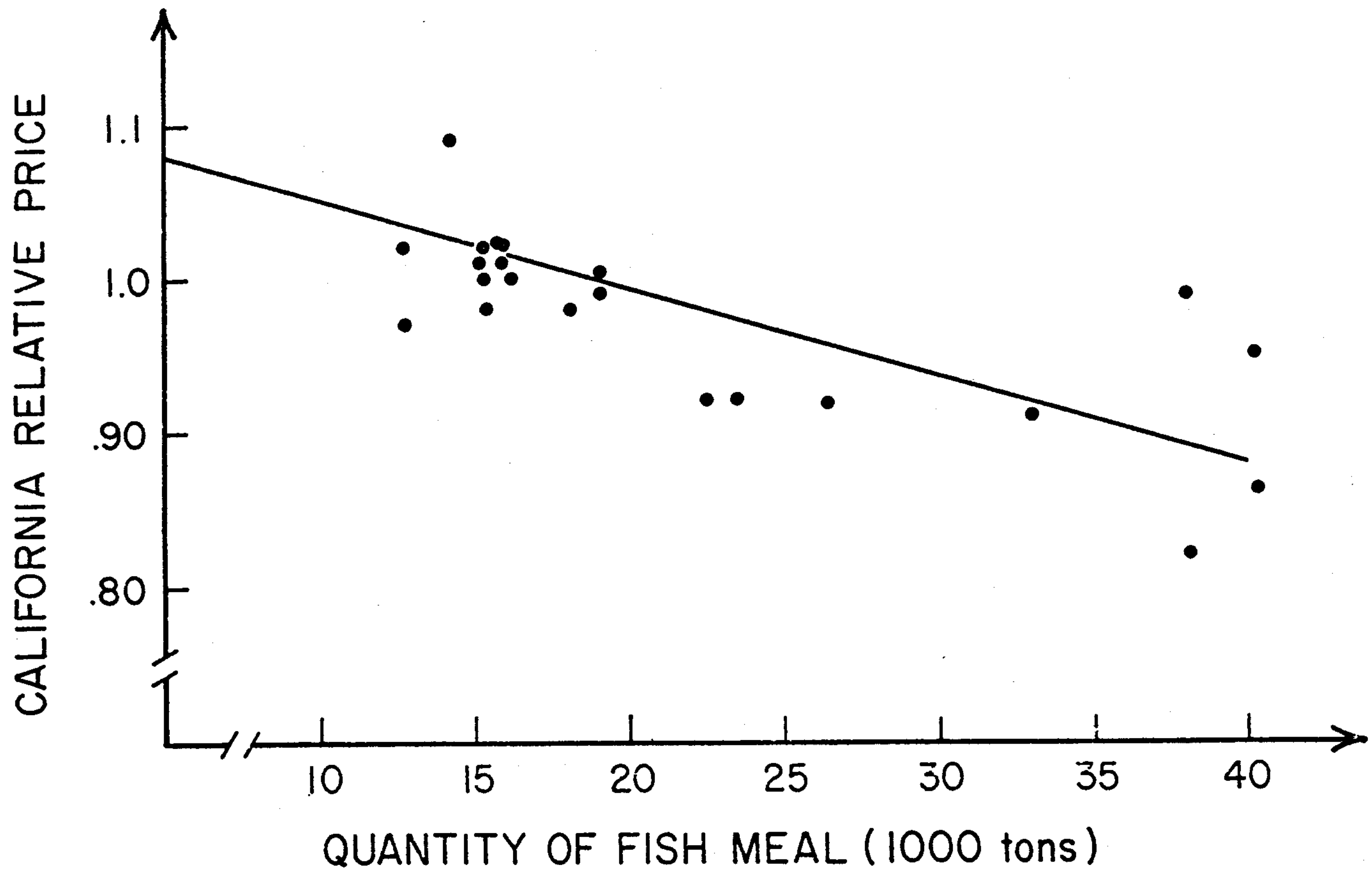

Figure 2. Plot and regression curve for California fish meal; California price is relative to U.S. average price.

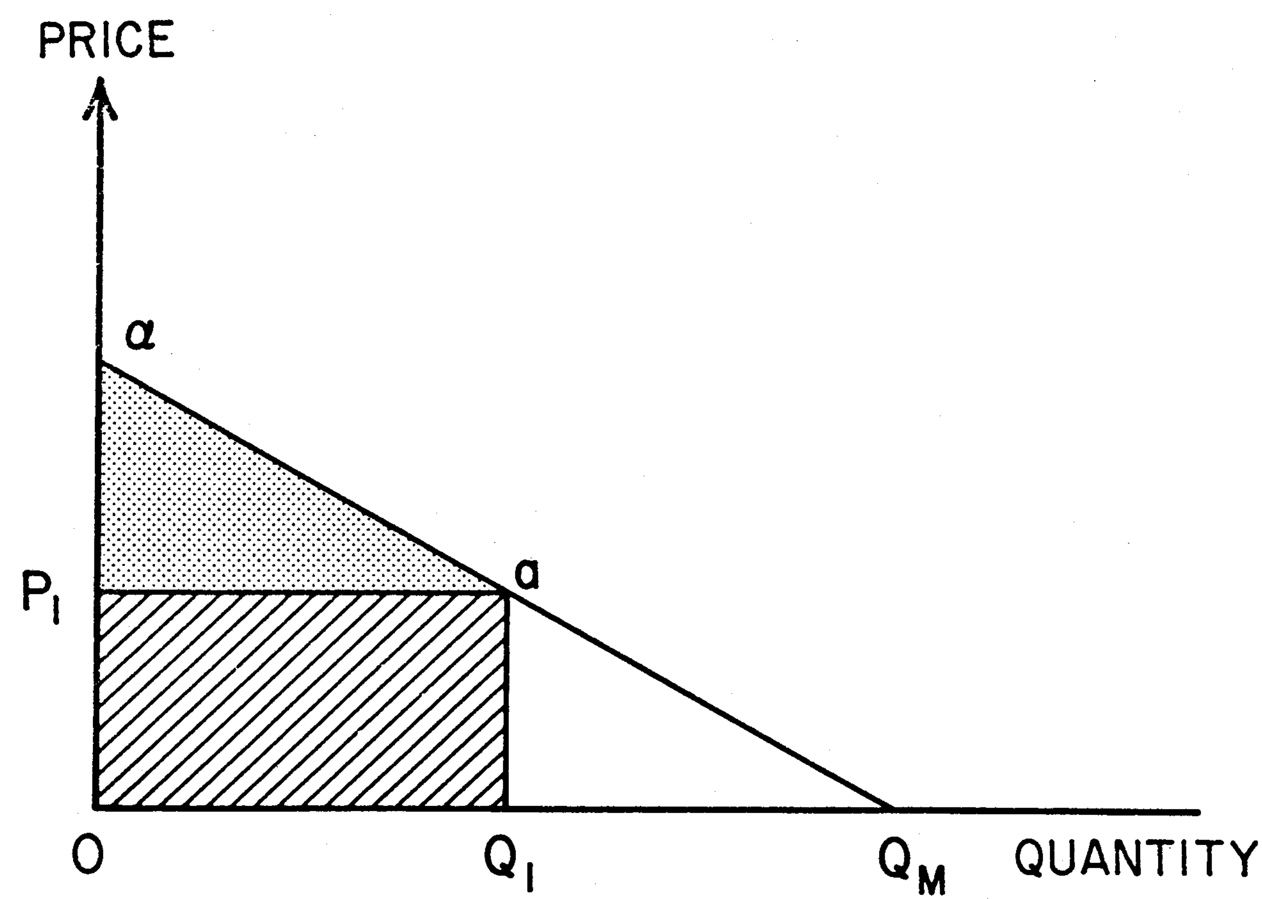

Figure 3. Hypothetical demand curve illustrating sales revenue (cross-hatched area) and consumer's surplus (dotted area).

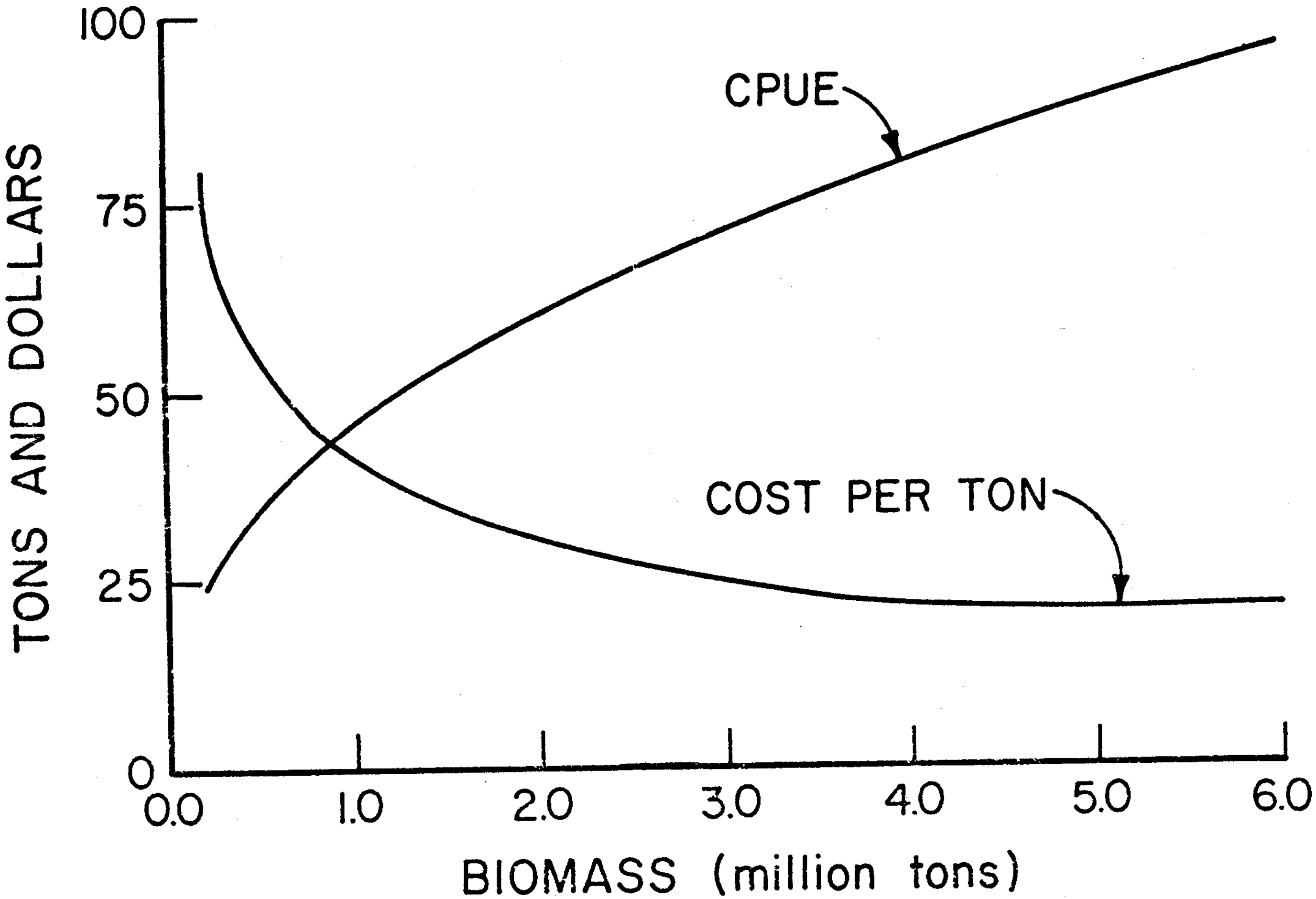

Figure 4. Relationship of catch per unit effort (CPUE) and cost per ton to anchovy biomass

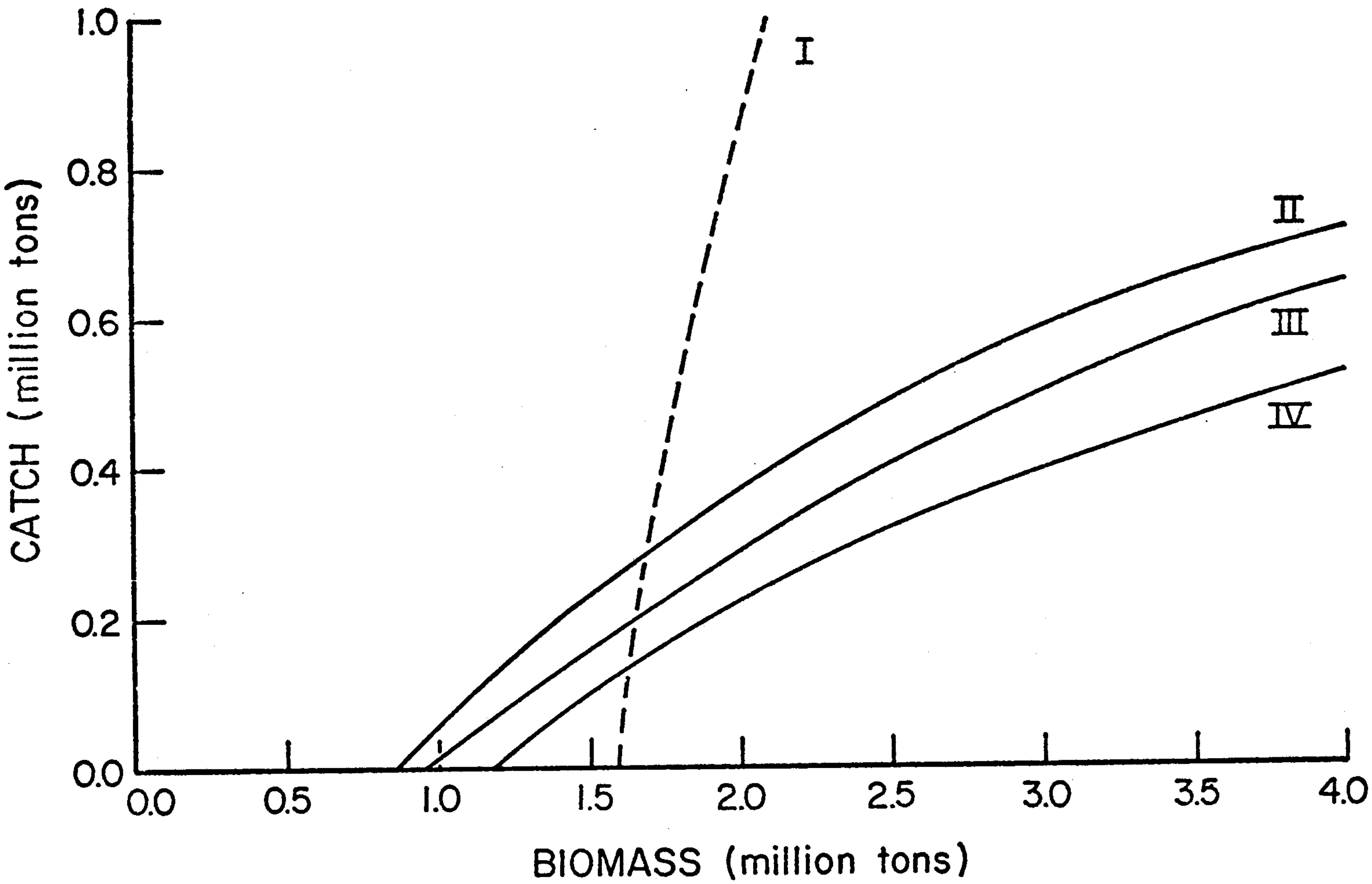

Figure 5. Optimal harvest policies for Maximum Catch Objective (I) and for Economic yield objective with 100 percent U.S. share (II), 70 percent U.S. share (III) and 50 percent U.S. share (IV).

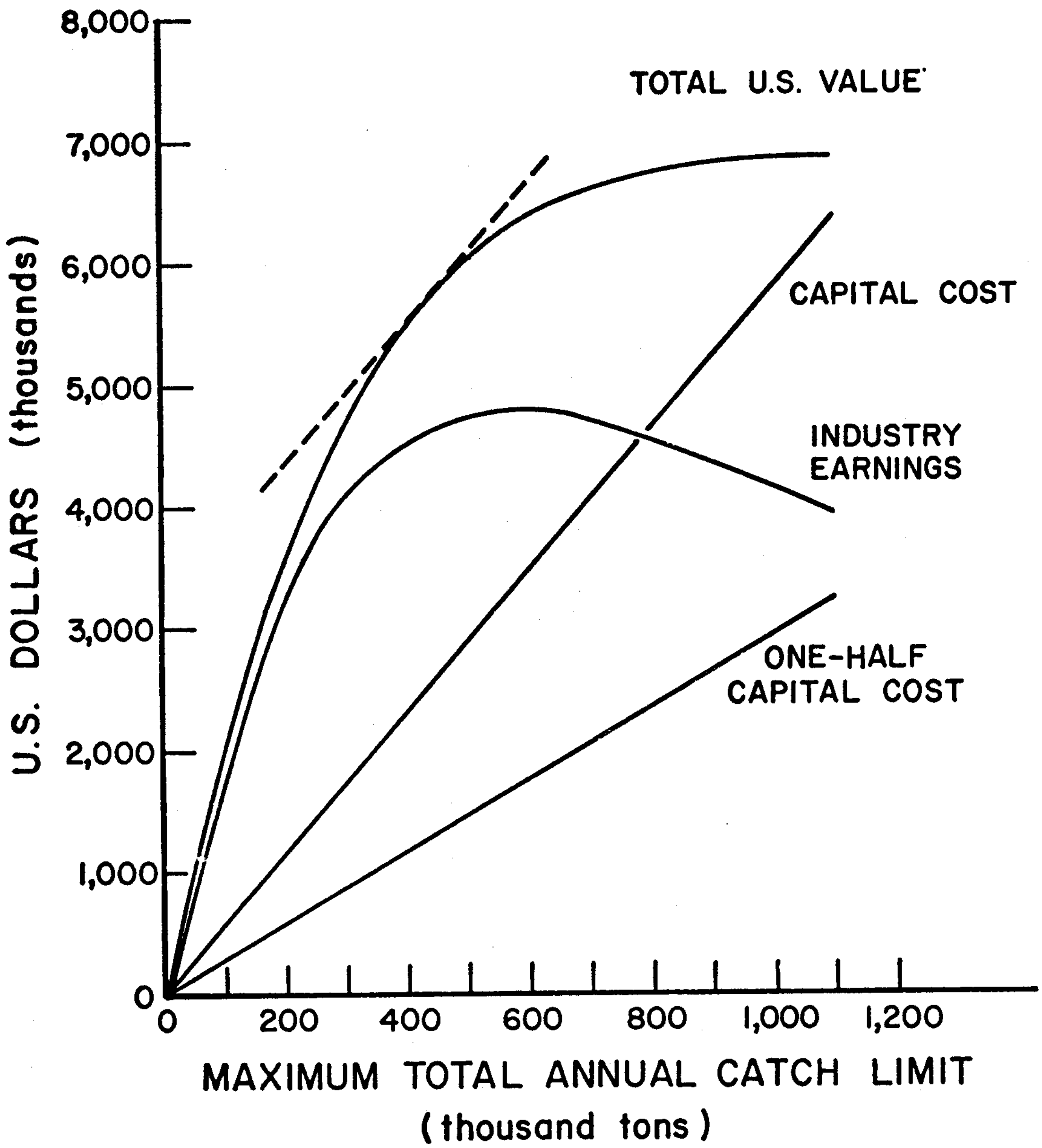

Figure 6. Expected economic returns and costs related to catch capacity with Option 2 harvest policy and 70 percent U.S. share of the catch.

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APPENDIX VII

THE PROPORTION OF THE SPAWNING BIOMASS OF THE ANCHOVY CENTRAL SUBPOPULATION IN MEXICO AND U.S. 200-MILE FISHERY ZONES

The Proportion of the Spawning Biomass of the Anchovy Central Subpopulation in Mexico and U.S. 200-Mile Fishery Zones

The central subpopulation of northern anchovy, Engraulis mordax, is a fishery resource shared by the United States and Mexico. An annual harvest quota based on the estimated current spawning biomass would have to be divided between U.S. and Mexican fishermen under cooperative U.S.-Mexico management. One possible criterion for such a division is the fraction of the estimated spawning biomass that is in Mexico or U.S. 200-mile jurisidction. Since the estimated biomass is proportional to the number of anchovy larvae estimated by the CalCOFI surveys, this fraction can be derived from regional larva census data.

This stock extends from approximately San Francisco (38^{o}N) in the north to about Punta Baja (30^{o}N) in the south. This range is contained in 8 CalCOFI regions totaling approximately 166,300 square nautical miles (nm^2) (Figure 1). The 200-mile Mexico-U.S. boundary cuts through the lower portion of regions SCI-07, SCO-08 and SCS-09 as shown in Figure 1. The boundary is described by the line connecting the following coordinates.

$32^{o}35'22.11''$N. lat., $117^{o}27'49.42''$W.long.
$32^{o}37'37.00''$N. lat., $117^{o}49'31.00''$W.long.
$31^{o}07'58.00''$N. lat., $118^{o}36'18.00''$W.long.
$30^{o}32'31.20''$N. lat., $122^{o}51'58.37''$W.long.

Approximately 2,400 nm^2 or 11.94% of the 20,100 nm^2 in region SCI-07; 1,000 nm^2 or 8.33% of the 12,000 nm^2 in region SCO-08; and 4,800 nm^2 or 16.67% of the 28,800 nm^2 in Region SCS-09 are south of the international boundary. For purposes of this report, 100% of the anchovy larvae for the offshore regions BCO-13 and BCS-14 were assumed to be in the central subpopulation. The division between the central and southern subpopulations is considered to be near Punta Baja at 30^{o}N for the inshore area. The offshore division between the two subpopulations has not been described.

The annual anchovy larvae census for the 8 regions encompassing the central subpopulation are given in Table 1 for the 19 CalCOFI years from 1951 to present. The portion of larvae in Mexico's jurisdiction were prorated based on the percent of surface area in the three regions SCI-07, SCO-08 and SCS-09 south of the boundary. This assumes that the larvae in the regional census are uniformly distributed over the region, although larva density is probably lower in the southern end of these regions. For purposes of this report, this assumption should be adequate for a first approximation. For the first six years, 1951-1956, when the biomass estimates were below 1 million tons, the percentages were 40% for Mexico and 60% for U.S. (Table 2). For the period 1957-1961 when the estimated biomass ranged between 1 and 2 million tons, the percentage off Mexico decreased to 28%.

For the period 1962-1975, the average percentage changed only slightly to 29% off Mexico and 71% off the U.S. The percentages though for 1972 and 1975 were 41% and 46% off Mexico, respectively. The overall mean for the 19 years is 32% off Mexico and 68% off the U.S. If the annual percentages are weighted by estimated annual biomass, the weighted mean percentage is 30% off Mexico and 70% off the U.S.

MacCall, Alec D. 1976. Density dependence of catchability coefficient in the California Pacific sardine, Sardinops sagax caerulea, purse seine fishery. Mar. Res. Comm., Calif. Coop. Ocean. Fish. Invest.Rep.18: 136-148.

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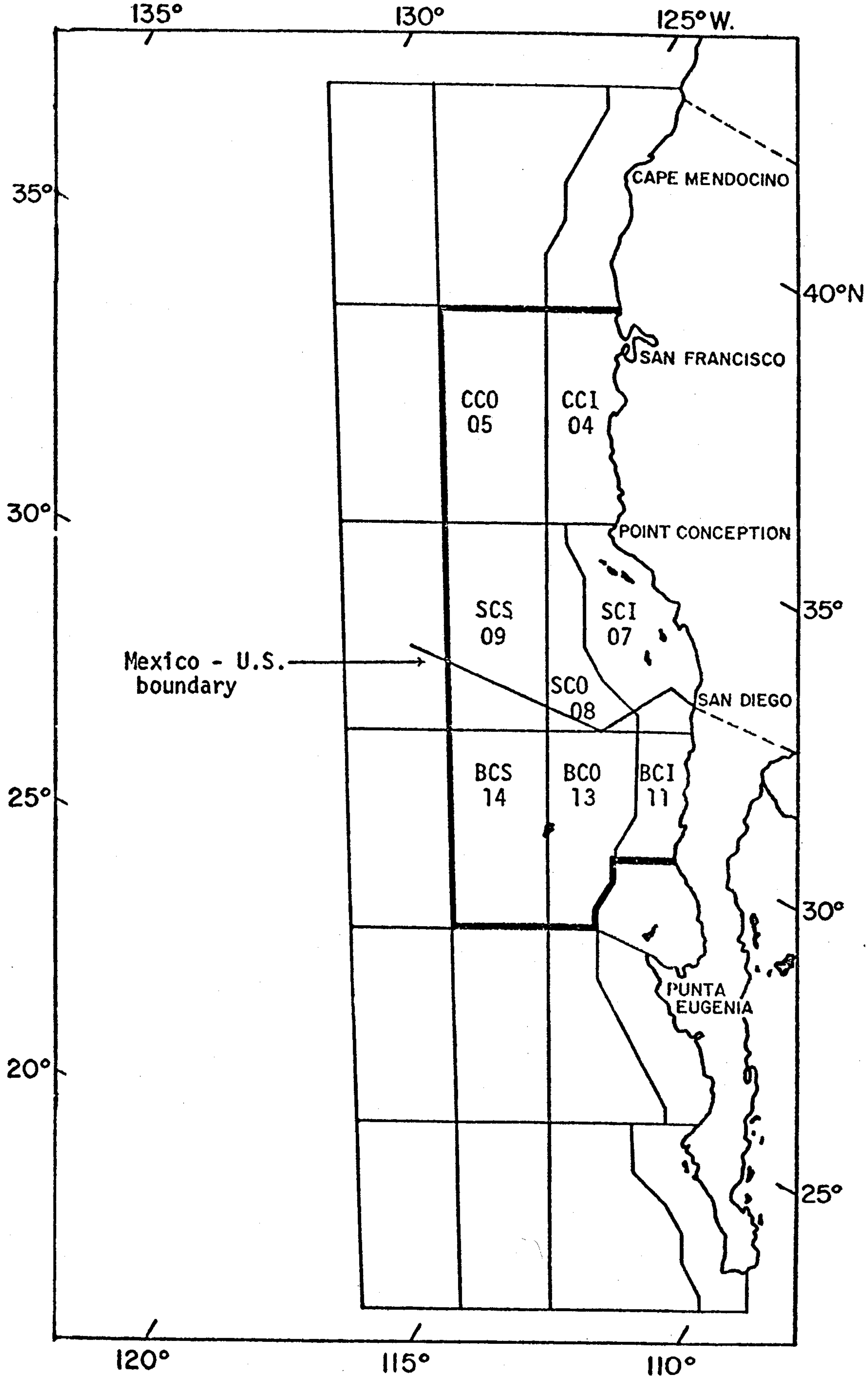

Figure 1. CalCOFI regions encompassing the range of the central subpopulation of northern anchovy.

Since spawning biomass is proportional to larva census, it can be inferred that, on the average, 30% of the spawning biomass of the anchovy central subpopulation is within Mexico's 200 nm fishery jurisdiction at the time of spawning. Mais (1974) made a general observation that during the spawning season in late winter and early spring anchovy schools tended to be further to the southwest. If this is the case, then the 30% off Mexico as determined by the larva surveys might be an overestimate for other times of the year, particularly during the fall when fish are most available in the San Pedro Channel off Los Angeles.

Table 1. Number of anchovy larvae in billions in U.S. and Mexico waters from CalCOFI surveys, 1951-1975

		CCI 04	CCO 05	SCI 07	SCO 08	SCS 09	BCI 11	BCO 13	BCS 14	Total	
1951	Total	33	53	1212	30	0	215	82	216	1,841	
	U.S.	33	53	1067	28	0				1,181	64%
	Mexico			145	2	0	215	82	216	660	36%
1952	Total	8	69	942	10	4	367	196	4	1,600	
	U.S.	8	69	830	9	3				919	57%
	Mexico			112	1	1	367	196	4	681	43%
1953	Total	1	0	3779	98	6	1017	305	2	5,208	
	U.S.	1	0	3328	90	5				3,424	66%
	Mexico			451	8	1	1017	305	2	1,784	34%
1954	Total	944	0	4696	377	445	1151	219	3	7,835	
	U.S.	944	0	4135	346	371				5,796	74%
	Mexico			561	31	74	1151	219	3	2,039	26%
1955	Total	10	0	4075	294	32	3240	715	262	8,628	
	U.S.	10	0	3588	270	27				3,895	45%
	Mexico			487	24	5	3240	715	262	4,733	55%
1956	Total	221	0	2252	433	75	656	950	357	4,944	
	U.S.	221	0	1983	397	62				2,663	54%
	Mexico			269	36	13	656	950	357	2,281	46%
1957	Total	80	21	9067	581	1071	984	137	19	11,960	
	U.S.	80	21	7984	533	892				9,510	80%
	Mexico			1083	48	179	984	137	19	2,450	20%
1958	Total	1903	1272	6901	1434	722	1898	937	20	15,087	
	U.S.	1903	1272	6077	1315	602				11,169	74%
	Mexico			824	119	120	1898	937	20	3,918	26%
1959	Total	3242	999	6931	1894	1255	675	442	2	15,440	
	U.S.	3242	999	6103	1736	1046				13,126	85%
	Mexico			828	158	209	675	442	2	2,314	15%
1960	Total	382	490	4096	3454	1369	3444	1695	783	15,713	
	U.S.	382	490	3607	3166	1141				8,786	56%
	Mexico			489	288	228	3444	1695	783	6,927	44%
1961	Total	662	313	2559	1947	3333	2084	710	219	11,827	
	U.S.	662	313	2253	1785	2777				7,790	64%
	Mexico			306	162	556	2084	710	219	4,037	34%
1962	Total	815	10	10540	6426	5955	3951	2423	262	30,478	
	U.S.	815	10	9282	5891	4962				20,960	69%
	Mexico			1258	535	993	3951	2423	262	9,422	31%
1963	Total	1944	107	11353	6896	13025	4513	4811	758	43,407	
	U.S.	1944	107	9997	6322	10854				29,224	67%
	Mexico			1356	574	2171	4513	4811	758	14,183	33%

(continued)

Table 1. (continued)

		CCI 04	CCO 05	SCI 07	SCO 08	SCS 09	BCI 11	BCO 13	BCS 14	Total	
1964	Total	3221	1488	10513	4951	8359	660	326	81	29,599	
	U.S.	3221	1488	9258	4539	6966				25,472	86%
	Mexico			1255	412	1393	660	326	81	4,127	14%
1965	Total	775	0	21986	7818	8712	3693	2675	1881	47,540	
	U.S.	775	0	19361	7167	7260				34,563	73%
	Mexico			2625	651	1452	3693	2675	1881	12,977	27%
1966	Total	2874	496	24481	4343	1742	2213	287	16	36,452	
	U.S.	2874	496	21582	3981	1452				30,385	83%
	Mexico			2899	362	290	2213	287	16	6,067	17%
1969	Total	998	72	28422	9202	1364	3993	1495	350	45,896	
	U.S.	998	72	25028	8435	1137				35,670	78%
	Mexico			3394	767	227	3993	1495	350	10,226	22%
1972	Total	504	250	18429	6980	2016	7662	4255	2516	42,612	
	U.S.	504	250	16229	6399	1680				25,062	59%
	Mexico			2200	581	336	7662	4255	2516	17,550	41%
1975	Total	218	3	18074	13694	1004	12081	9927	151	55,152	
	U.S.	218	3	15916	12553	837				29,527	54%
	Mexico			2158	1141	167	12081	9927	151	25,625	46%

Table 2. Percent of anchovy larvae in U.S. and Mexico waters from CalCOFI surveys, 1951-1975.

Year	Biomass estimate	U.S. %		Mexico %	
	(in thousand short tons)				
1951	180	64		36	
1952	156	57		43	
1953	510	66	60%	34	40%
1954	768	74		26	
1955	846	45		55	
1956	485	54		46	
1957	1172	80		20	
1958	1479	74		26	
1959	1514	85	72%	15	28%
1960	1540	56		44	
1961	1159	64		34	
1962	2986	69		31	
1963	4254	67		33	
1964	2901	86		14	
1965	4659	73	71%	27	29%
1966	3572	83		17	
1969	2999	78		22	
1972	2784	59		41	
1975	3603	54		46	
Arithmetic mean		68%		32%	
Weighted mean		70%		30%	